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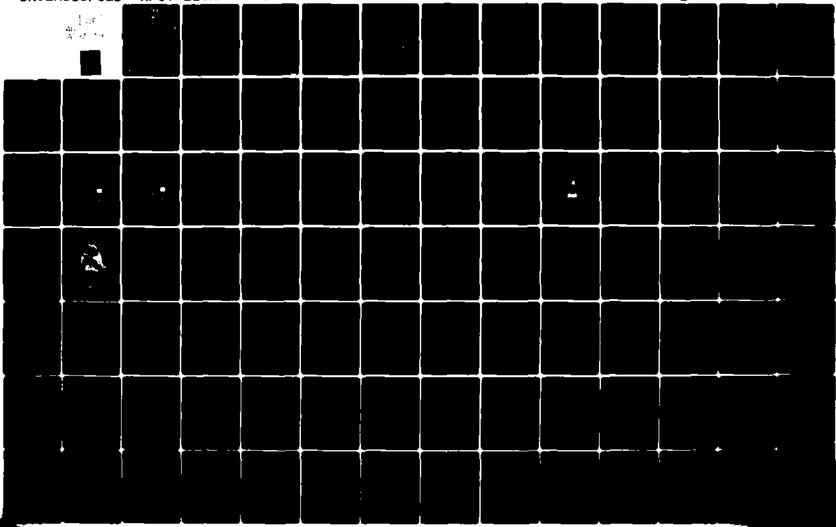

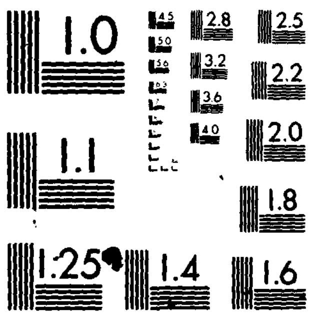

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AN ANALYSIS OF WATER-TO-AIR HEAT PUMP SYSTEMS FOR USE IN GOVERNMENT FACILITIES

Robert G. Fretzs, Captain, USAF

LSSR 74-80

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Energy consumption is an important issue for government managers. Examined in this thesis is one source of potential energy savings: a method of heating and cooling buildings. Water-to-air heat pumps are analyzed and cost comparisons to conventional heating/cooling systems (gas, fuel oil, electric resistance, and air-to-air heat pumps) are made. The theory of heat pump technology is presented to show how water source heat pumps achieve improved efficiencies over conventional systems. Sources of and disposal of water to support the systems are discussed. Cost comparisons are presented based on computer simulations and fuel cost graphs. Twenty-one percent of U.S. energy consumption is used to heat and cool buildings. Water-to-air heat pumps provide a 30-50 percent savings over other systems. Therefore, a potential 10 percent savings in total energy consumption exists through the use of water source heat pumps.

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AN ANALYSIS OF WATER-TO-AIR HEAT PUMP SYSTEMS FOR USE IN GOVERNMENT FACILITIES

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Management

By

Robert G. Fretzs, BS
Captain, USAF

September 1980

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Captain Robert G. Fretzs

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CHAPTER I

INTRODUCTION

Energy has become one of the most important issues of the world today. In the past, cheap, abundant energy supplies have supported the industrial, transportation, commercial, and residential needs of the world. However, recent escalations in energy prices, the predicted depletion of oil supplies, and the after effects of the Three Mile Island nuclear incident in 1979 have caused much concern about energy resources. As a result, many solutions are being sought to help alleviate any future energy crisis. New technologies, conservation, and alternate sources are being sought by governments as well as private companies and individuals. All areas of energy use are being analyzed in an attempt to reduce consumption or to use energy more efficiently. Those areas with the highest usage may have the greatest potential to yield significant reductions in consumption.

Several sources (Calm, 1980; Dorf, 1978; Gass, 1977) have shown that nearly 21% of the total energy use in the United States is for heating, ventilation, and air conditioning. This compares with 26% for all transportation (19% high way, 4% air, 2% marine, and 1% rail) and 37-42% for all industrial usage. Another 6-8% is used to produce domestic hot water while only 4% is used in lighting. Reductions in the use of energy to heat and cool factories, businesses, and homes could have a significant impact on total energy consumption.

Various methods to reduce energy consumption include developing alternate sources and developing more energy efficient equipment. Alternate sources include solar, coal gasification, wind, and geothermal energy. These sources require further development and some are very localized products. Equipment efficiencies are improving with new equipment, plus retrofit items are now available to make existing equipment more efficient.

The United States government has been supporting research and development of new energy sources and is interested in improving equipment efficiencies (U.S. DOE, 1980). It may be possible that both directions will combine for a synergistic effect on reducing energy consumption. One of the energy sources being analyzed is geothermal energy.

Geothermal energy is usually identified with select areas of the world where a surface source is found, such as steam geysers or hot springs. Hot rock areas also have been identified below the surface in certain areas. These geothermal areas produce heat in the form of steam at temperatures around 250°C or hot fluids above 200 calories/gram (Considine, 1977). These heat sources are the typical geothermal sources being developed and can be used for electrical generation or space heating.

Only certain areas of the world, however, will have the potential to be developed as hot geothermal sources. Problems of extreme high temperatures, high pressures, and corrosive materials have to be dealt with in developing these sources, and new technology must be used. Another potential geothermal source exists in greater quantity and may have far more potential. Cold geothermal or hydrothermal sources contain a potential energy supply within ground water resources, reservoirs, and rivers. The energy contained within these water resources can be utilized through the use of water-to-air heat pumps to obtain heat for winter use or to use as a heat sink for cooling purposes in the summer.

Several companies manufacture water-to-air heat pumps (see Appendix A), but they are mainly used for commercial purposes and are not widely used in individual homes. Southern states appear to be the primary marketplace in the U.S. for residential water-to-air heat pumps at this time. Since ground water temperatures are higher than winter air temperatures and lower than summer air temperatures, a potential energy source may be available by using water-to-air heat pumps throughout the entire continental United States. Since heating, ventilation, and air conditioning use 21% of the nation's energy, substantial savings may be available by joining geothermal water resources and the efficiencies of heat pumps.

Statement of Problem

Energy consumption in government facilities can be reduced by using proper insulation, weatherstripping, storm doors, and storm windows. After these actions are completed, additional energy savings can be made by making heating and air conditioning systems more efficient. Without waiting for new technological breakthroughs, what can be done now to increase efficiency? Specifically, what is the potential for and under what conditions is it possible to achieve significant increases in energy efficiencies and savings in government facilities by using water-to-air heat pumps? If these savings can be obtained, base and facilities managers should be aware of the potential savings available to them. Energy usage has become critical, and the ability to reduce energy consumption should not depend on extensive research of new, sophisticated systems, especially if more energy efficient systems already exist. If steps can be taken to take advantage of known capabilities, they should be taken to obtain the marginal savings available at this time.

Research Objectives

The overall objective of this thesis is to determine if water-to-air heat pumps can provide an economically effective answer to reducing energy consumption and, therefore, energy costs in government facilities.

Another objective is to provide background information to familiarize the reader with heat pump technology, available equipment, present uses of heat pump systems, and potential problems and advantages.

An additional objective is to provide a qualitative comparison of water-to-air heat pump systems with conventional systems such as electric resistance, air-to-air heat pumps, fuel oil, and natural gas.

This thesis is directed toward the manager and not the specialist in heating and air conditioning systems. As such, the engineering side of the system is from the layman's point of view. The manager should be concerned about the potential of the process, so more emphasis is placed on the analysis of the system and not the technical process itself.

Research Questions

As a homeowner and manager within the Air Force, the author is concerned with energy consumption in both homes and buildings maintained by the government. The topic of this thesis was approached to answer the following questions:

1) To what extent can geothermal energy in the form of water resources be used to reduce heating and air conditioning costs?
2) How does the water-to-air geothermal heat pump work and what makes it efficient?
3) Can these heat pumps be used throughout the U.S. in government facilities?
4) How do water-to-air heat pumps compare economically with conventional heating and cooling systems?

The answers to these questions will be addressed in the remaining chapters of this thesis. The next chapter will explain the data sources used, a description of comparative systems that are evaluated, limitations, assumptions, and the approach of this thesis and how it can be applied to government facilities.

CHAPTER II

METHODOLOGY

Introduction

The subject of using geothermal energy to heat facilities is not a new subject; the subject of heat pumps is not new either. What is new is the integration of low temperature, geothermal energy and water source heat pumps to heat and cool facilities and to do it at a substantial savings over conventional systems. Since it is a new subject which is just beginning to gain acceptance in the heating and air conditioning profession, limited information has been written in normal literature sources. An attempt was made by the author to identify the subject with geothermal energy, but the subject was more associated with heat pump technology and water resources.

Data Sources

A library literature search was made which resulted in some information. Initially, articles were found in Popular Science, and some of the technical magazines addressed theory of heat pumps. These sources referenced heat pump manufacturers and the National Water Well Association of Worthington, Ohio. Also, contractors in Dayton, Ohio were involved in the equipment, such as John W. Jones, World Energy, Inc., who has written some manuals on water source heat pumps and has done extensive work in the area. Various interviews with National Water Well Association personnel produced further sources of information at Argonne National Laboratory, Battelle Columbus Laboratories, the Texas Energy Council, and the U.S. Department of Energy (DOE). Invaluable information was received from heat pump manufacturers, the Defense Documentation Center, and various governmental agencies. The author also attended the National Ground Water Geothermal Heat Pump Conference and Exposition at Ohio State University and had the opportunity to listen to lecturers and talk with contractors from across the country. The National Water Well Association is a focal point of information on the subject and has been involved with several DOE studies and research projects. Most all sources referenced the National Water Well Association as the best source of information. A study being conducted by the National Water Well Association under DOE Contract 78-01-4278 was used extensively, and fully supported the cost comparisons made in this thesis.

Description of Comparative Systems

An analysis which compares water-to-air heat pumps with other systems must be conducted under conditions where equal outputs are achieved. In this thesis, comparative systems include electric resistance heating, natural gas furnace, fuel oil furnace, and air-to-air heat pump systems. In order to compare total use throughout the year, air conditioning systems are added to the electric resistance system and the fossil fuel systems. However, in some cases only heating systems were compared. The analysis includes equations developed by the author which provide fuel cost ratios. The ratios are then presented in graphical form with breakeven lines to illustrate fuel cost comparisons.

The National Water Well Association study (DOE, 1980) was also used to obtain data to support part of the comparative analysis. In the study, nine cities throughout the U.S. were used to compare total heating and cooling costs. For each city a comparison was conducted using five total systems as follows:

- electric furnace/electric central air conditioning
- oil furnace/electric central air conditioning
- natural gas furnace/electric central air conditioning
- air-to-air heat pump/reversible cycle
- ground water heat pump/reversible cycle

The ground water heat pump system was also broken down into subsystems associated with the number of wells required to be drilled. One system assumed an available well, one considered drilling an injection well, and the final version considered drilling both a source well and an injection well. Each system was sized for the specific location plus each location was compared using local energy costs and equipment costs. The basic construction of the modeled building (a residential home) was kept constant throughout all locations to compare different heating/cooling loads required for different climates.

The data reported in the DOE study did not include energy required to supply domestic hot water; however, the author was able to obtain data to show the total energy cost to heat, cool, and generate hot water. All systems used electric resistance to generate hot water except the gas system, which used gas, and the ground water heat pump system, which used a desuperheater in the refrigerant loop.

Limitations and Assumptions

The nature of the subject made it necessary to seek out information from manufacturers and commercial organizations which support the use of water source heat pumps. As a result, some bias was evident in some of the literature. Limited original sources of information also resulted in interrelated data.

Comparisons between different systems are very dependent on local conditions and specific energy loads required. Applying results across broad areas is questionable because each region of the country will have different inputs and demands on the total system. The National Water Well Association used computer simulation in their report to the Department of Energy to show cost comparisons of different space-conditioning systems in nine different cities of the U.S. By using computer simulation, the variable inputs can be reduced and controlled, resulting in a more accurate measure for comparison. The data collected from the DOE study was assumed to be correct; however, it was preliminary data from an unpublished study and was subject to change before final submittal to the DOE.

Approach and Applicability

Although this thesis is directed toward government use, the energy loads involved can be used in any building, and the theory of the system can be applied in any facility. Source data was not directly involved with government facilities; however, any system or theory discussed can be applied to government facilities. Specific reference is not made to government facilities, but direct application can be made.

The next chapter will provide background information about heat pump systems. It explains the theory of the systems, how efficiencies are measured and can be improved, and how various water sources can be used. Actual application will be discussed along with advantages and disadvantages. In order to understand the operation of the system, one must first explore the technology involved in heat pumps.

CHAPTER III

BACKGROUND AND SYSTEM REVIEW

Theory of Heat Pump Technology

A heat pump is a mechanical device that "pumps" heat from a cooler location to a warmer location. The process is accomplished by using a refrigeration loop to connect the two locations. Refrigerators and freezers are examples of the most abundant use of heat pump technology. Also, air conditioners are examples of heat pumps. Normally, these heat pumps have been used to transfer heat from one location to another, warmer location, causing the source location to become cooler. By switching the heat source and heat sink, one can also heat an area with the reverse process.

Reverse cycle air conditioners and air-to-air heat pumps have become common in the U.S. in recent years. They use air as both the heat source and heat sink. In the summer, they transfer heat to the outside; in winter they absorb heat from the outside air and "pump" it inside. Air can contain heat even when it is cold; heat is only absent at absolute zero, or 460° below 0°F.

Heat energy naturally flows from a warmer location to a cooler location, so a heat pump is used to "pump" heat against the natural flow to a warmer location. A refrigeration loop is used to transfer this heat.

Figure 1 shows a typical heat pump used to heat a house. As the refrigerant is pumped through the loop, it changes from a liquid to a gas and back to a liquid. During the process, the refrigerant transfers heat from the outside to the inside. More specifically, the refrigerant absorbs heat when it is in the outdoor coil and changes from a liquid to a low temperature, low pressure vapor. It then flows to the compressor which superheats the refrigerant to a high temperature, high pressure vapor. The refrigerant flows to the indoor coil where heat is released to the air. This changes the refrigerant to a high temperature, high pressure liquid. It then flows through an expansion valve or capillary tube which reduces the pressure and changes the refrigerant back to a low temperature, low pressure liquid. It is now ready to absorb outside heat and start the process over. The flow in the system is caused by the compressor pumping the refrigerant and the pressure differences within the loop. The only energy required in the system is used to operate the compressor and the fans in the indoor and outdoor coils.

Figure 2 shows the same system in the cooling cycle with the refrigerant flowing in the opposite direction. In this case, heat is absorbed at the indoor coil and transferred to the outdoor coil, where it is rejected. The mechanism which is able to make the system reverse is the four-way valve or reversing valve.

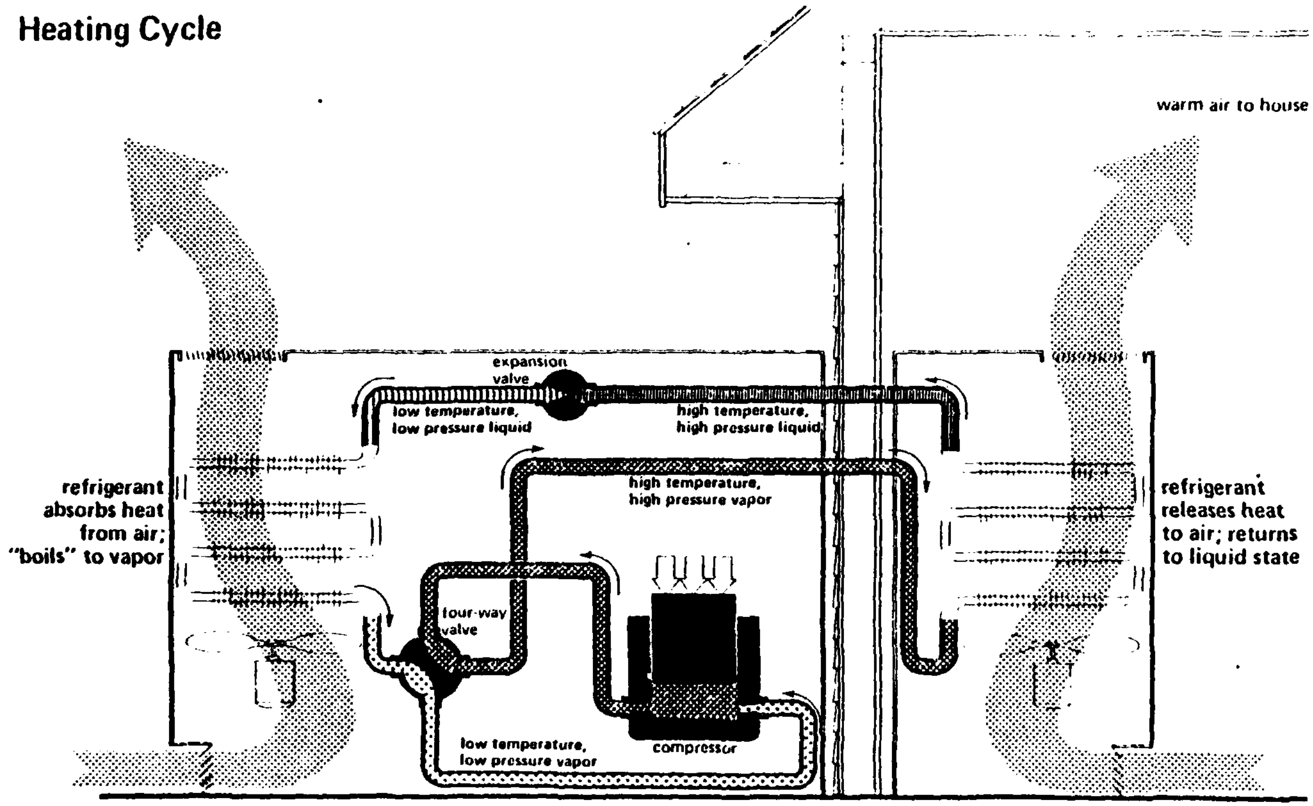


Figure 1

Heat Pump - Heating Cycle [DOE, 1979, 3]

Cooling Cycle

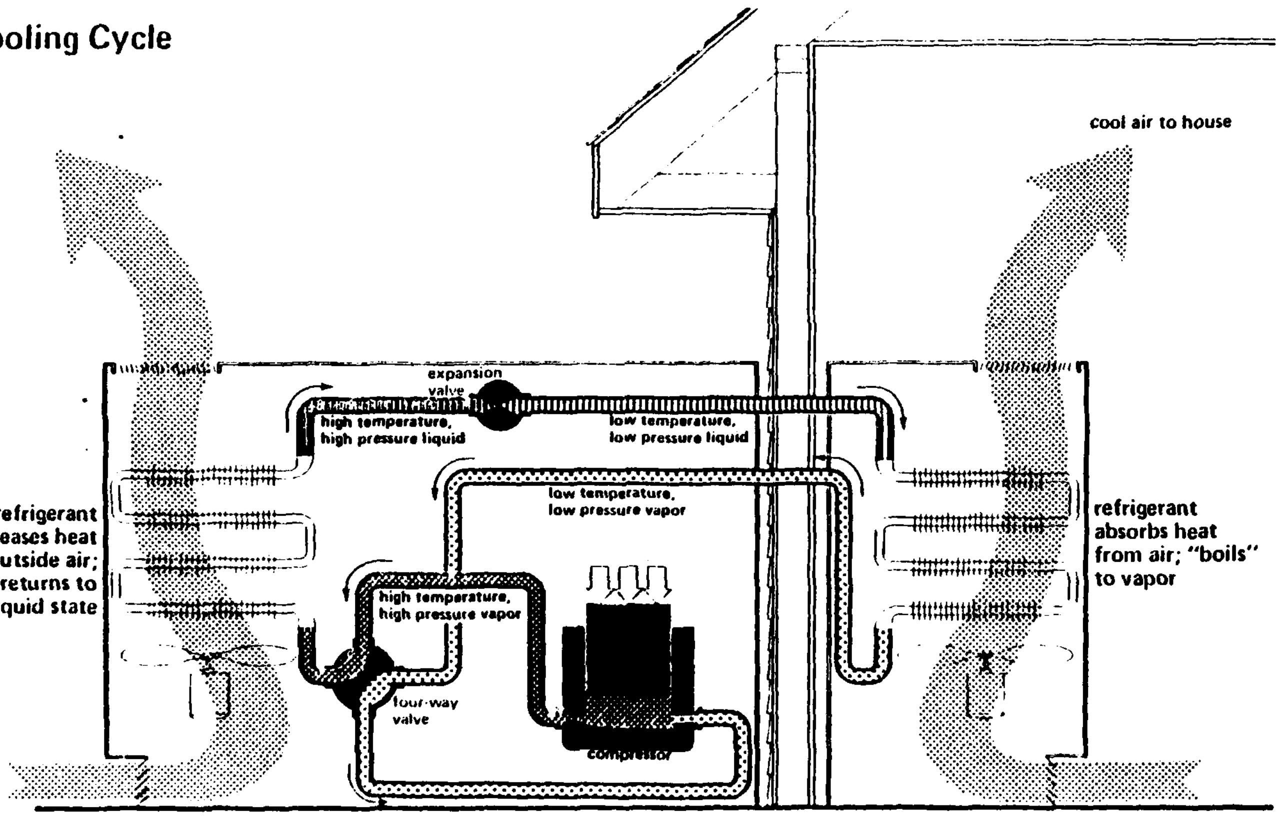


Figure 2

Heat Pump - Cooling Cycle [DOE, 1979, 4]

Efficiency

The efficiency of heat pumps is measured in terms of coefficient of performance (COP). The COP is defined as the ratio of the energy output obtained, divided by the energy input used. The units of energy are measured in British thermal units (Btu).

$$COP = \frac{\text{Btu of Heating/Cooling Output}}{\text{Btu of Energy Input}}$$

Heat pumps are the only conventional heating systems which return more heat than they consume. This is accomplished by transferring available heat from one source to another rather than creating heat as most systems do. Typically, a heat pump can deliver two to three times the energy output that other systems can, with the same energy input (see Table I). Depending on the costs of the input energy, potential savings can be obtained by using heat pumps. Table I shows estimated COPs for various sources.

TABLE I

COPs for Various Sources

Systems	COP		
	High	Low	Avg*
Propane	.65	.45	.65
Fuel Oil	.70	.40	.60
Natural Gas	.80	.45	.65
Electric Resistance	1.00	.95	.95
Air Source Heat Pump	2.70	1.00	1.70
Water Source Heat Pump	5.20	2.70	3.20

*Based on frequency
Sources: American Air Filter, undated; Mahan, 1980; NWWA, c; Persons, 1978; SOESI, undated; TETCO, 1980; Utah, 1979.

Limitations

Heat pumps using air as a heat source/sink have limitations, however. The amount of heat available in the air decreases with decreasing outside air temperature. Figure 3 shows a typical heating load for a building in relation to outside air temperature. Also shown is the heating capacity of an air-to-air heat pump. As one can see, as the temperature drops, an increase in heating demand occurs; unfortunately a decrease in heat pump capacity also occurs. The point at which the curves intersect is the balance point. At temperatures below this point the heat pump is not able to supply enough heating capacity to satisfy the heating load of the building. To overcome the lack of capacity, supplemental heat is required, usually in the form of electric resistance heating strips. The use of supplemental heat reduces the efficiency of the heat pumps substantially, as the system is now creating heat in addition to transferring it.

A similar effect results in the cooling mode when heat is being rejected to high temperature outdoor air. However, there is no backup system for cooling, and the equipment has to work harder to reject the heat. This causes poor efficiencies in the system. What can be done to improve efficiencies of the air-to-air heat pump system?

Using a source/sink which does not vary as much as outside air temperature can improve efficiencies. Ground water temperatures have been found to be very stable

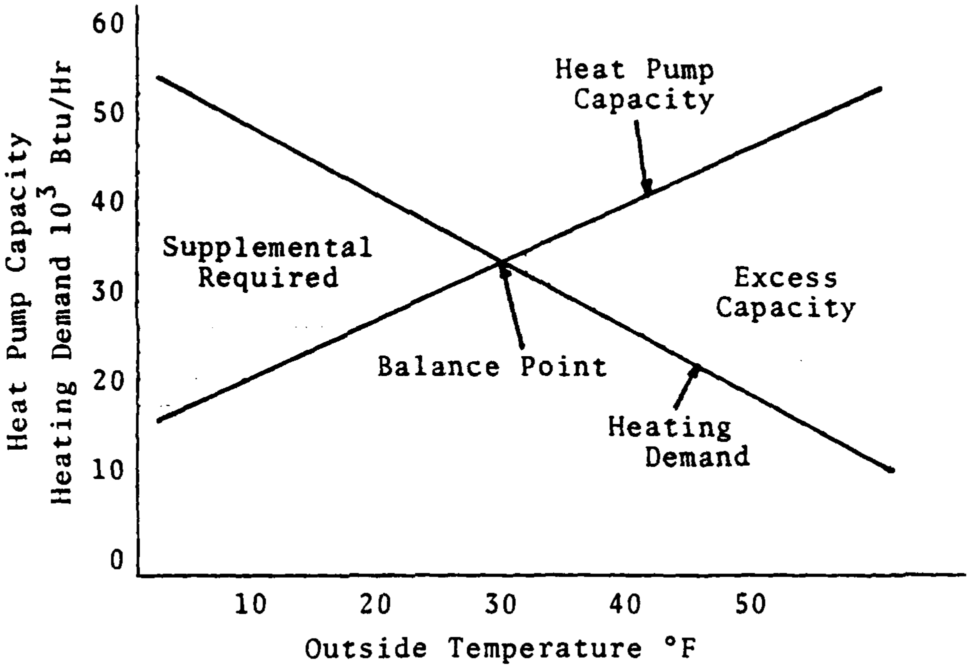


Figure 3

Heating Load Vs Outside Air Temperature
[NWWA, d, 2]

throughout the year despite the outside air temperature. Ground water is usually close to the mean ambient air temperature of most areas and runs between 80°F in the South to about 44°F in the North. Figure 4 shows the average temperature of ground water at depths between 50 and 150 feet below the surface.

Water as a Source/Sink

Using water as a heat source/sink has many advantages. Along with its stable temperature, water is able to store more energy than any other substance (NWWA, c). Water has a specific heat of energy equal to one which is the highest specific heat of any common substance. Specific heat is the

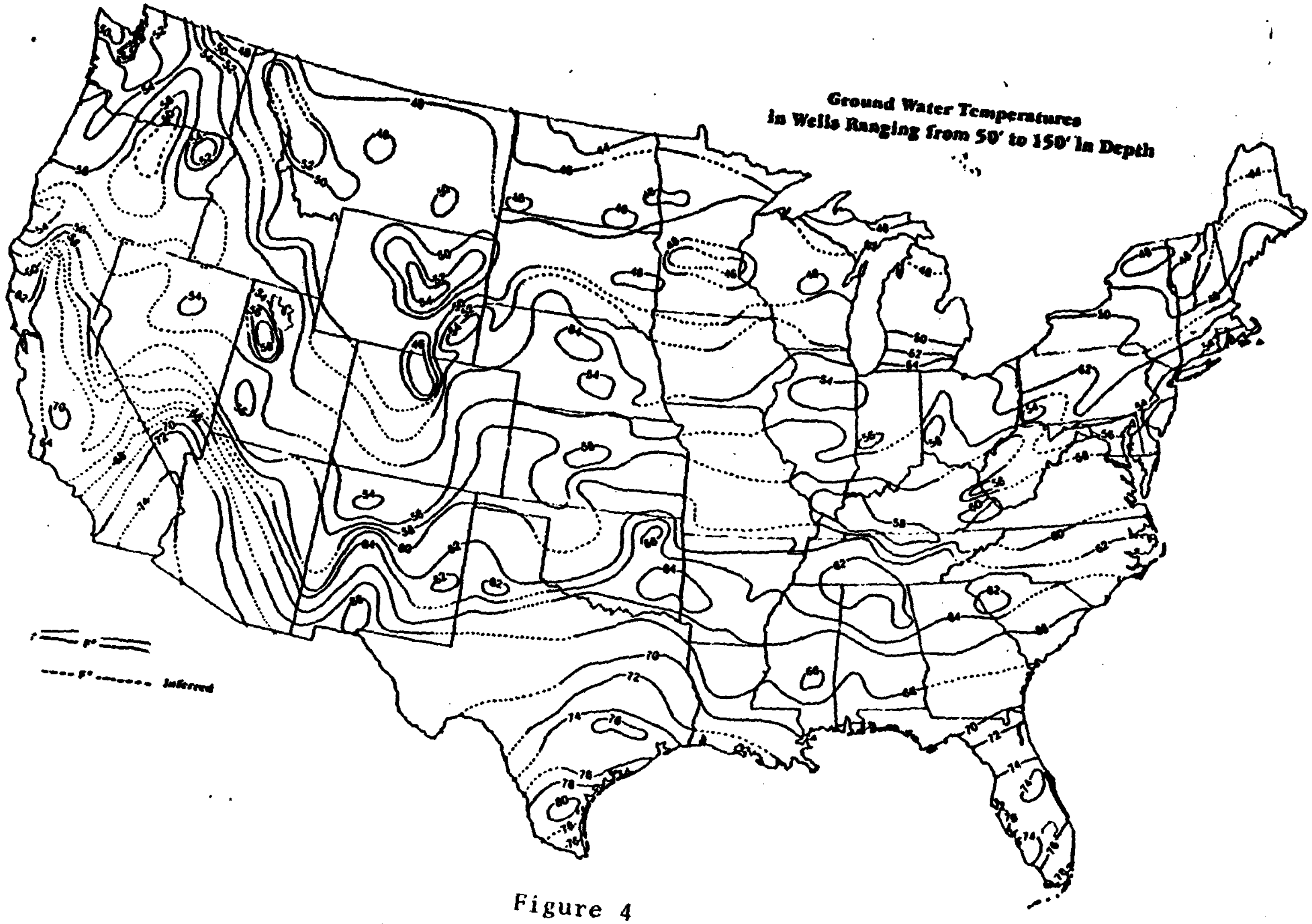


Figure 4

Ground Water Temperatures
[Courtesy of NWWA]

amount of energy required to raise the temperature of a unit weight of any substance 1°F. As a comparison, lead has a specific heat of .0297. If one pound of lead is heated by 1 Btu, its temperature is increased by 34°. If one pound of water is heated by the same Btu, its temperature increases only 1°. To release the Btu energy, water gives off 1 Btu for every 1° loss per pound while lead gives off 1 Btu for every 34° loss per pound. Water will give off more energy than any other substance when its temperature is lowered by 1°, or it will absorb more energy when it is heated by 1° (NWWA, c).

When compared to air as an energy source, water is far superior. Air has a specific heat of .018, so it can only absorb or release 1/50 the amount of energy that water can. Fifty times more air by weight must pass through a heat pump to produce as much heat as the same amount of water. This gives water source heat pumps a definite advantage over air source heat pumps.

Water Source Heat Pump

The water source heat pump operates exactly like the air source heat pump except that the outdoor coil is substituted for a water-to-refrigerant coil. This water-to-refrigerant coil is usually placed inside the main indoor unit to provide a compact package which is not subject to weather extremes. As a result, reliability and service life are expected to be better (American Air Filter, undated).

Figures 5 and 6 show typical water-to-air heat pump systems.

The advantage of adding water as the source/sink is to increase the efficiency of the system. Since water can absorb or give off more energy per degree per pound than any other substance, more energy can be exchanged per unit of water than any other substance. Also, since ground water sources remain at a fairly constant and moderate temperature throughout the year, they produce a constant capacity to support a heating load. Unlike the air source heat pump, when a water source heat pump is sized for a heating/cooling load of a building, the capacity will not change with outside air temperature changes (see Figure 7).

Depending on the water source and the heating demand, supplemental heat is often not required and often not included in the basic equipment. This results in reduced equipment and operating costs. Savings can also be increased by using a direct cooling system in which only the water pump and blower operate. This saves compressor energy in the process. Figure 8 shows a typical heat pump system using direct cooling.

The efficiency gains obtained by water source heat pumps are indicated by the increased coefficient of performance. Table I shows, on the average, almost twice the efficiency of air source heat pumps, three times that of electric resistance, and five times the efficiency of fossil fuels. These efficiencies can be misleading, however, unless the cost of the fuels is also considered. This will be addressed in the next chapter. What can be seen, however, is that the heat pumps

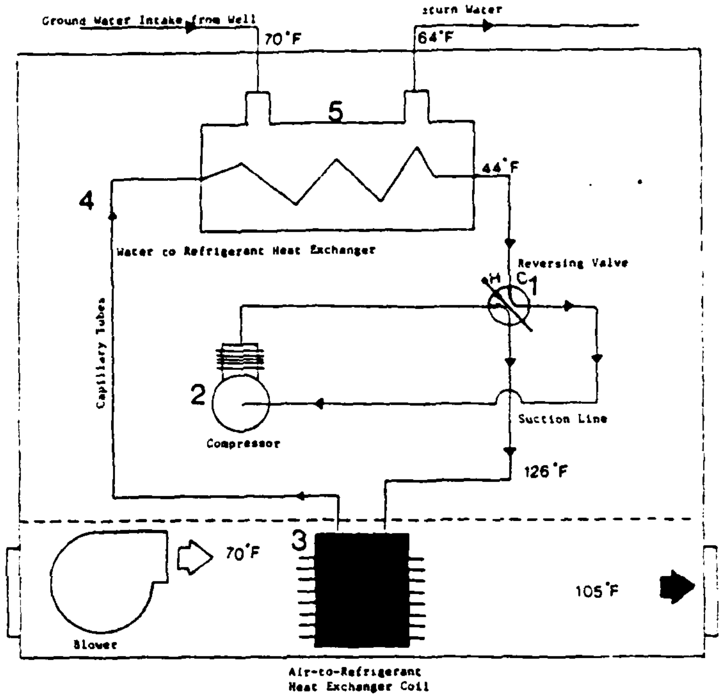


Figure 5
Water Source Heat Pump, Heating [NWWA,a,43]

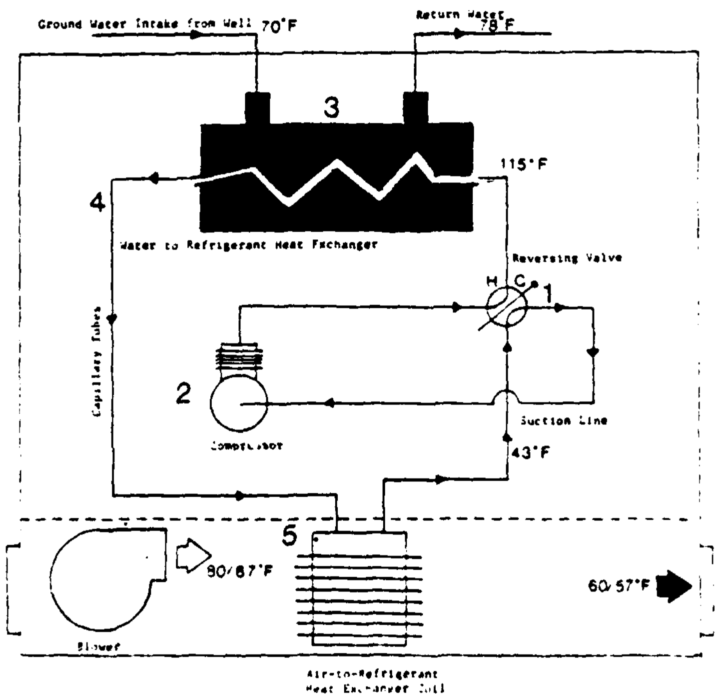


Figure 6
Water Source Heat Pump, Cooling [NWWA,a,43]

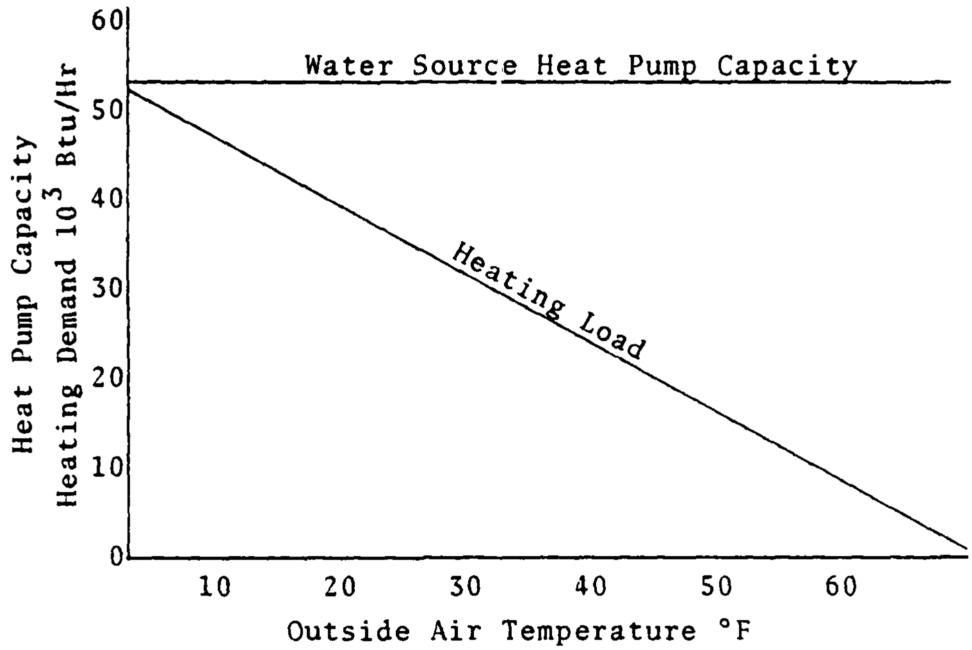


Figure 7

Water Source Heat Pump Capacity
[NWWA, d, 6]

and electric resistance all use the same power source, and operating costs are inversely related to efficiencies.

Additional Benefit

In addition to heating and air conditioning, heat pumps can produce domestic hot water by using the superheated refrigerant that is produced by the compressor. Figure 9 shows how this heat exchanger fits into the system. Although this system is usually found only on water source heat pumps, hot water heaters are available that use air source systems as well. Northrup Inc. (1980) now markets a heat pump, hot water heater which is self-contained and reportedly shows savings of 50 percent over electric resistance heaters. When added to

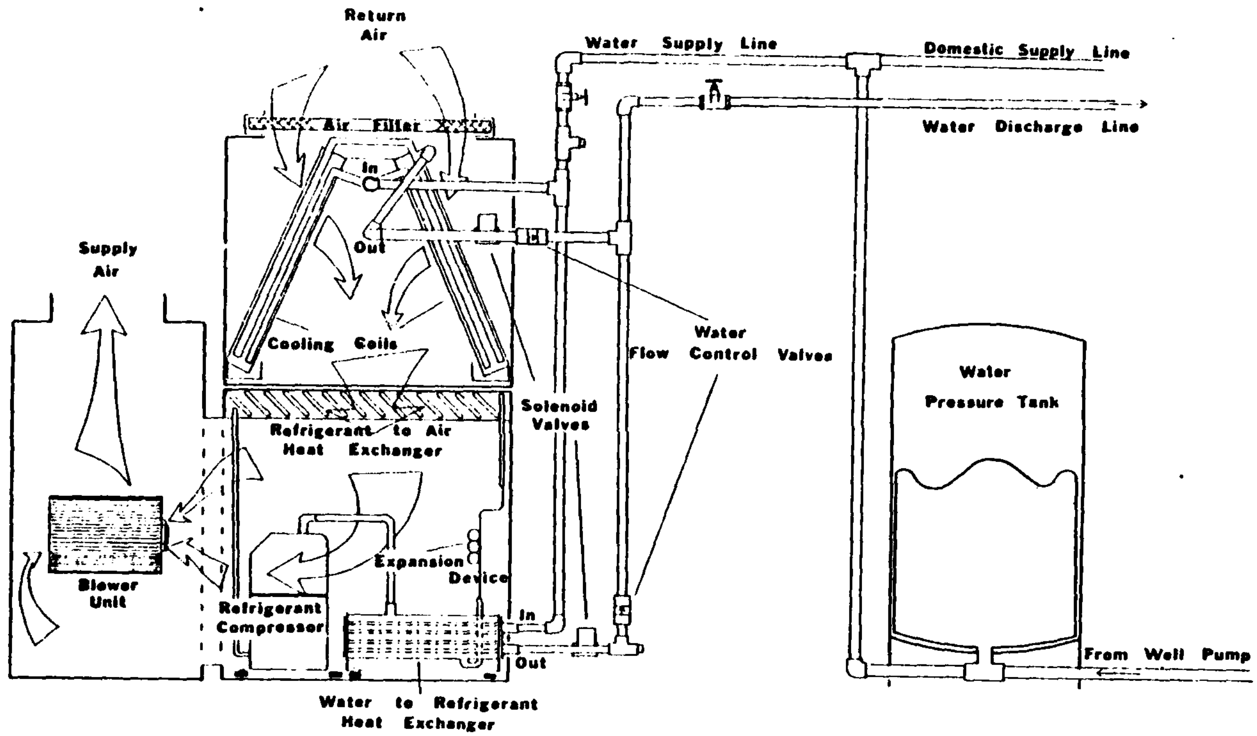


Figure 8

Direct Cooling System [TETCO, undated, 8]

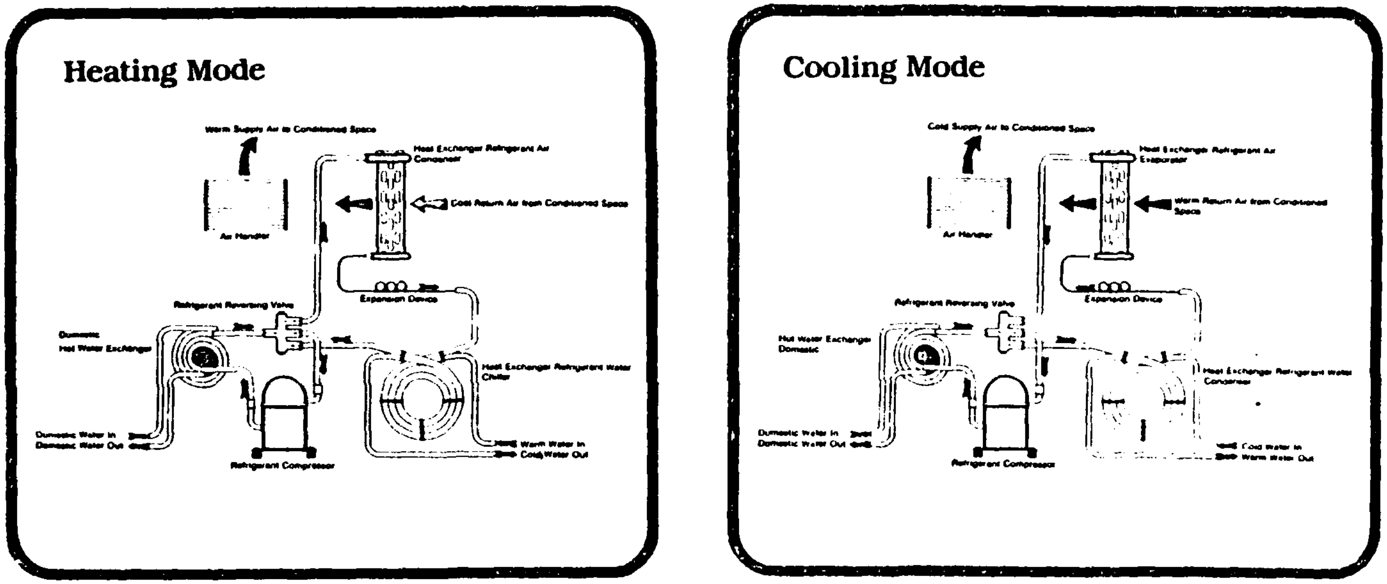


Figure 9

Domestic Hot Water Generation [NWWA, c, 3] water source heat pump systems, the hot water generator does not reduce the efficiency of the system significantly. It has been reported that it is cheaper to run the air conditioner to produce hot water than to run an electric resistance hot water heater to produce hot water (Persons, 1978).

Water source heat pumps may be beneficial and may save energy, but they are dependent on the availability of water resources. Without the water in the system, the higher efficiencies cannot be obtained.

Water Sources

Water resources make the water source heat ,ump efficient. Water resources are abundant and can be found in underground aquifers, rivers, and reservoirs. A constant supply of water is ideal, but not necessary. Energy can be exchanged with the earth through the use of earth coils or geothermal wells. This section will explore the use of normal water sources and also some innovative sources of energy using water as an energy carrier.

Wells, Rivers, Reservoirs

One ideal source of water to support a heat pump system is an existing well. This is because it is an available resource waiting to be used, capital costs to procure the well have usually been paid, and the well has usually been proven to produce water. If a well is not present, one can probably be drilled. According to Tyler Gass of the National Water

Well Association, over 75 percent of the United States is capable of supporting ground water source heat pumps (Gass, 1978). Figure 10 shows the major aquifer areas of the U.S.

The amount of water needed to support a heat pump is dependent on the temperature of the water. It will take more water to extract heat from a 45° source than a 55° source as was apparent in the discussion on specific heat of energy. Heat pumps have been manufactured which will accept water temperatures from as low as 40°F with a water supply of 10 gallons per minute to provide 44,000 Btu/hour, or nearly 3.7 tons of capacity (TETCO, undated). This flow must be maintained while the heat pump is operating, but is not constantly necessary. Storage tanks have also been used to supplement low well yields down to one gallon per minute. In this case, the water is circulated in a closed system until the water reaches an unusable temperature, at which time new well water is used to displace the unusable water.

Another ideal source of water is existing rivers, ponds or other reservoirs. These are good sources because of the visible abundance of water and because they can be used both as a source and a storage area. The temperatures of these sources will vary more than ground water sources, but will usually still be available during the winter to support a heat pump. Even though a large reservoir may be frozen on the surface, the water near the bottom never falls below 38°F (Nielsen, 1977).

In order for the system to operate, it must receive

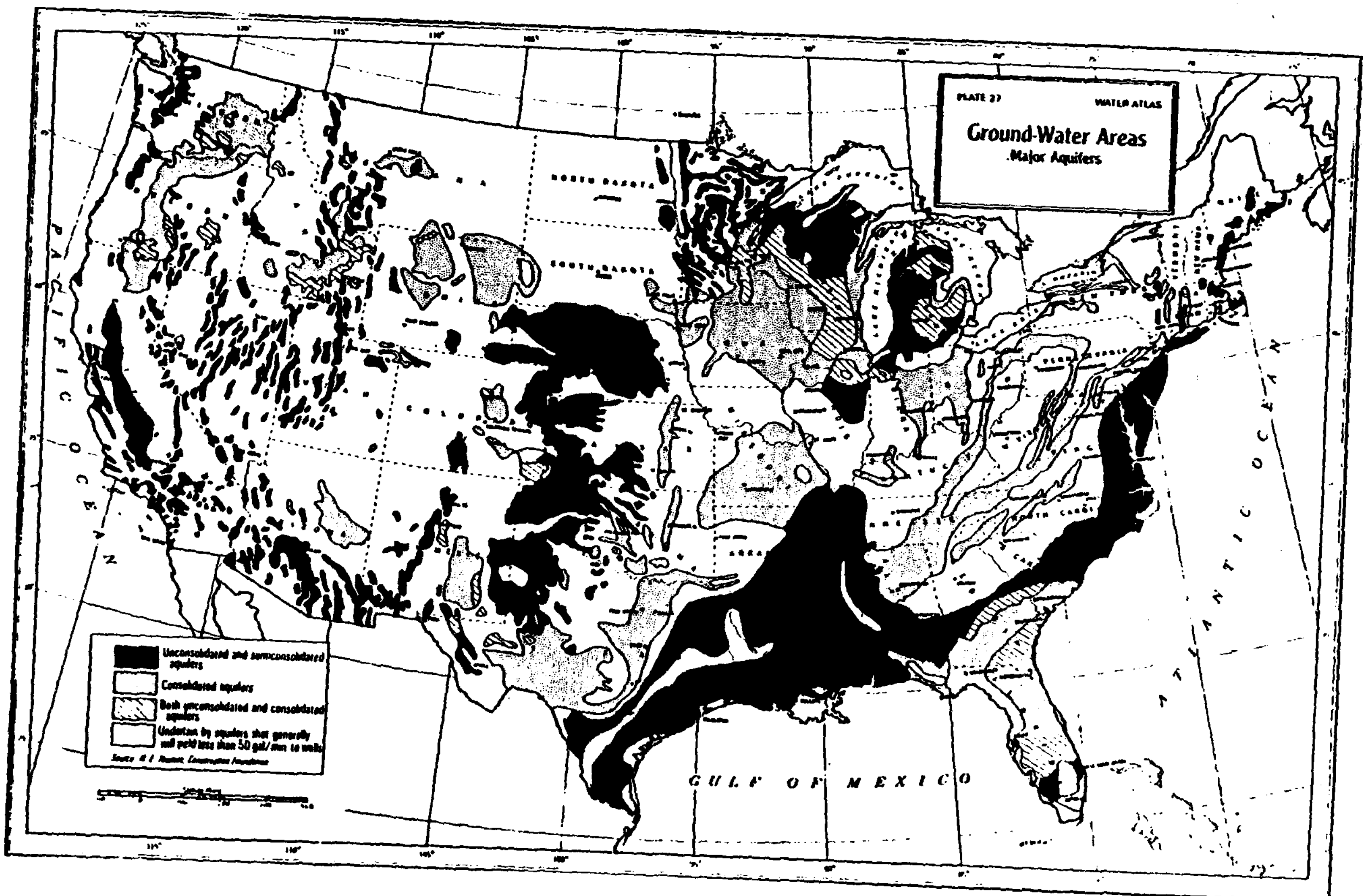


Figure 10

Ground Water Areas of U.S.
[Water Atlas, 1973, Plate 27]

water to extract or absorb heat and then reject the water out of the system. In the process, the rejected water will be cooled in the heating mode and heated in the cooling mode. The amount of temperature change is dependent on the rate of water flow. It is usually cooled 7° to 15°F in the heating process, and heated 10° to 30°F in the cooling process. The temperature reduction in heating, ΔT_h can be estimated using the following formula:

$$\Delta T_h = \frac{Q_h - (Q_h/COP_h)}{500\ F}$$

where

Q_h = heating capacity of the unit (Btu/hr)

COP_h = heating coefficient of performance of the heat pump

F = water flow rate (gallons per minute) [NWWA, d, 8]

The temperature rise in cooling, ΔT_c can be estimated by using another formula:

$$\Delta T_c = \frac{Q_c + (Q_c/COP_c)}{500\ F}$$

where

Q_c = cooling capacity of the heat pump (Btu/hr)

COP_c = cooling coefficient of performance of the heat pump (COP_c = Energy efficiency ratio (EER) ÷ 3.412)

F = water flow rate (gallons per minute) [NWWA, d, 9]

The numerator of these equations reflects the heat of absorption and heat of rejection, respectively, of the entering water. These values can be directly substituted if known. The effect of this temperature change can be important in the disposal of the water.

Disposal

After heat has been absorbed from or rejected to the water resource, the water must be disposed of. The disposal of the used water is dependent on several factors which include the capacity of the source, and environmental and legal restrictions.

The National Water Well Association recommends that the disposal water be returned to ground water resources by use of an injection well. This helps restore water resources through recycling. Injection wells should be located in different aquifers and located some distance apart to reduce the possibility of thermal pollution. The location of the injection wells depends on the local geologic conditions, and many studies have been conducted to determine proper spacing (Hildebrandt, Das Gupta & Elliott, 1979; Kazmann & Whitehead, 1980; Schaetzle, Brett & Seppanen, 1979; and Schockley, 1980). Usually 100 feet apart is deemed acceptable. With a two-well system, it is also possible to use one well for a heating source and the other for the cooling source, which helps balance any temperature changes in the aquifers. Figure 11 indicates how a two-well system would operate.

Environmental problems must also be considered in disposing of the water. Although the water is not changed

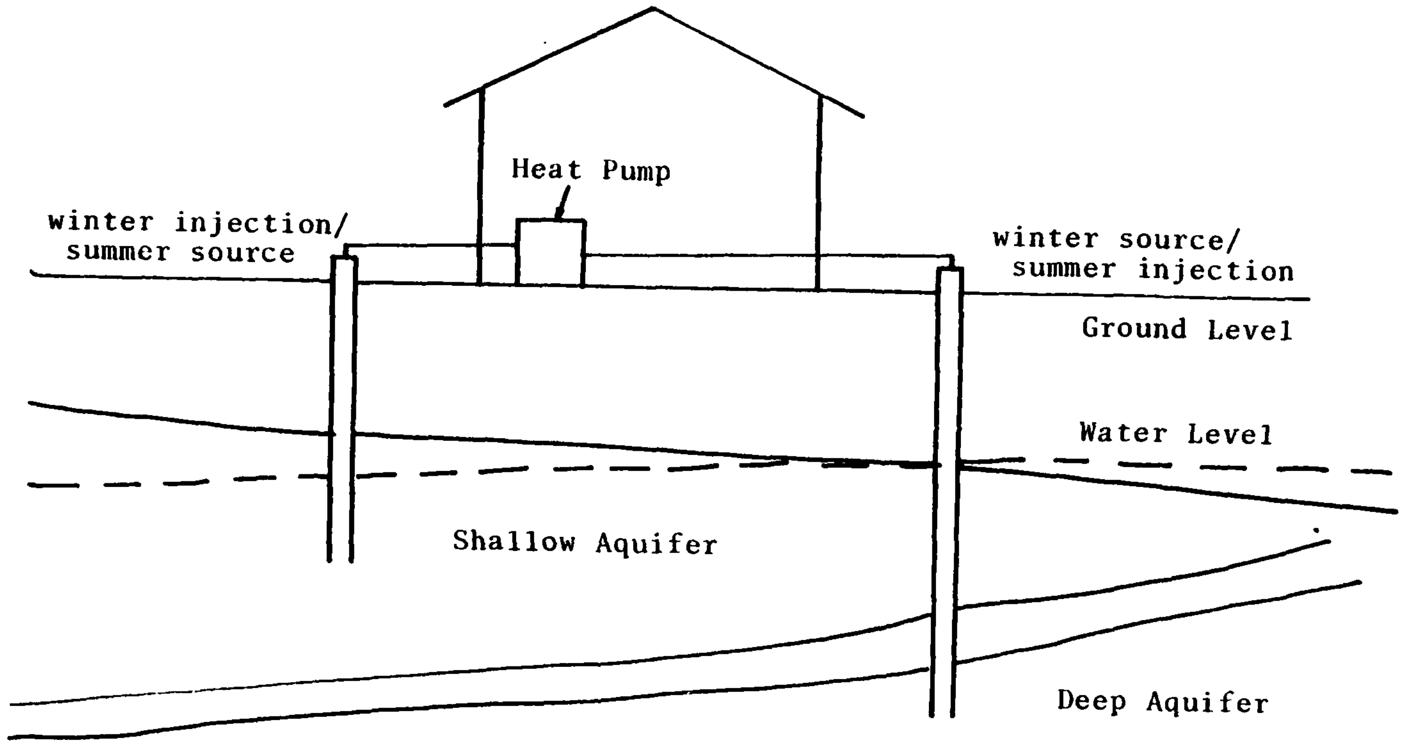


Figure 11

Two Well Heat Pump System

chemically, it does change in temperature. Large temperature changes can cause chemical alterations and can cause some environmental effects, but the small temperature changes resulting from heat pumps is not expected to create any problems. Mixing of aquifer waters can cause transfer of contaminant materials from a contaminated source to a clean source, so care must be taken in locating wells. Ground water heat pumps could probably reduce total pollution, however, because of the reduced use of fossil fuels and reduced air pollutants caused by their use (DOE, 1980).

Disposing of the water must overcome legal restrictions too. Federal, state, and local regulations must be observed. Laws regulate surface disposal as well as reinjection of water. Seven states (Arizona, Maine, Minnesota, Missouri, Oklahoma, Virginia, and Wisconsin) prohibit reinjection, while other states require permits (Miller, 1980). To overcome disposal and water quantity problems, other methods have been developed to replace consumptive use of water resources.

Earth Coupled Heat Exchanger

In regions of the country where consumptive use of ground water is prohibited by law or by nature, closed systems can be used to support the heat pump. One of these systems is the closed-loop earth coil. John W. Jones of Jones Heating and Cooling Company, Dayton, Ohio has been a proponent of the earth coil system and has developed innovative techniques to support the system. The earth coil system uses the heat of the earth to maintain the temperature of the water in the loop. The coil is buried below the frost line and requires 500 gallons of water per ton of capacity. To achieve maximum thermal exchange with the earth, a soaker system is included to keep the earth moist around the buried loop (Jones, 1980).

A variation of this idea is used by Geosystems, Inc. of Stillwater, Oklahoma. In conjunction with Oklahoma State University, Geosystems, Inc. has developed a coil system used below septic lateral fields. Figure 12 indicates how the system is designed. The earth coil lines are 4-inch, 160 psi PVC (plastic) pipe. Approximately 300 feet of pipe are required per ton of capacity (Partin, 1980). The earth coil systems are good in areas where wells cannot be drilled. Where wells can be drilled, but water is not available, Geosystems, Inc. has developed the geothermal well.

The geothermal well (Figure 13) can be used in areas that have inadequate water flow, but are wet enough to keep a well casing moist. In this system, a PVC casing is placed in the well hole and is sealed at the top and the bottom. The water circulates within the geothermal well by being drawn off the top and rejected at the bottom. As the water flows to the top, it exchanges heat with the earth. In this system, 100 feet of casing per ton of capacity are required (Partin, 1980).

It is interesting to note that more literature is available concerning the well applications with heat pumps

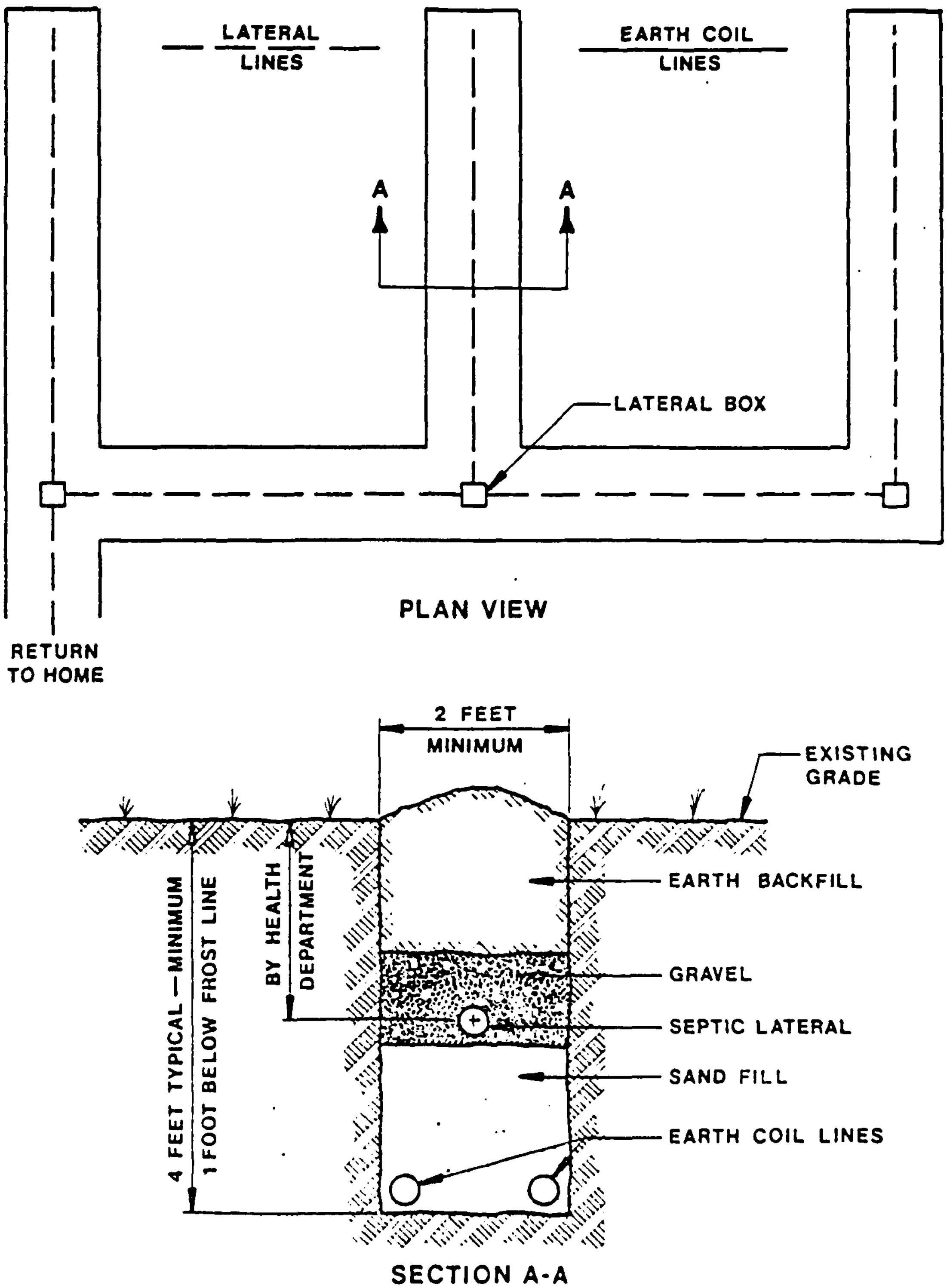


Figure 12

Earth Coil Plan and Cross Section
[Partin, 1980, 2]

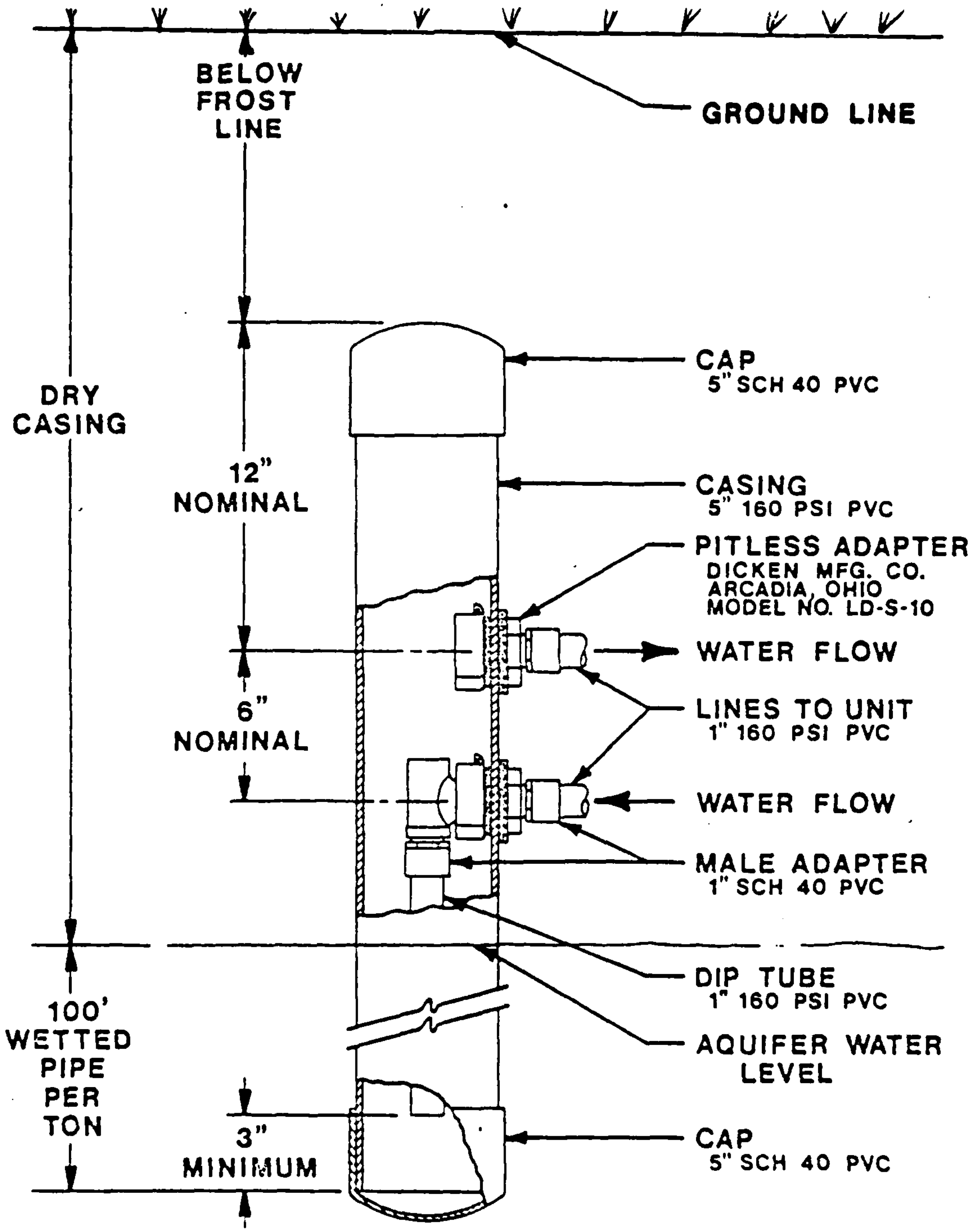


Figure 13

Geothermal Well Installation [Partin, 1980, 4] than the earth coil systems. This is probably due to commercialization of the water source heat pump by the National Water Well Association. Since the National Water Well Association is in business to support well drillers, the Association tends to encourage systems using wells. In the 1980 study for DOE, the National Water Well Association does not even address the earth coil systems; only ground water wells and geothermal wells are addressed. Each potential area should be examined to determine which system would be most appropriate to provide maximum efficiency.

Past Applications

The water-to-air heat pump is relatively new, but the theory has existed for some time, and several pioneering efforts were started years ago. The first residential heat pump was reportedly built in 1948 by Carl Nielsen, Professor of Physics at Ohio State University. He built a ground water heat pump to condition a 500 square feet vacation cottage. The unit produced 12,000 Btu per hour. After having success with the first heat pump, in 1955 Nielsen built a second ground water heat pump to condition 1,000 square feet on the lower floor of his home. This system produced 20,000 Btu on two kilowatts of electricity per hour and 2.5 gallons of water per minute. It is still in operation today after 25 years and has only had two minor maintenance problems--some scale blockage at a connecting pipe and replacement of the starting control (May & Gass, 1977).

In 1958 and 1959, Battelle's Columbus Laboratories installed commercial, centrifugal water chillers which were modified to accept well water as a source. These were installed based on predicted savings of life cycle costs. The system is still used today to condition four buildings with a total area of 317,000 square feet. The heat pumps are supplied by six wells; five are 50 feet deep and the sixth is 224 feet deep. The water is disposed of in the Olentangy River adjacent to the laboratory. The system has been highly successful and has supplied a COP of as high as 4.4 for cooling and 5.4 for heating (Fischer and others, 1979; Gannon, 1978; and Heiss, 1977).

In 1959, a Houston builder installed 40, three-ton ground water heat pumps in a subdivision of new homes. This was a new idea which had a good start. Unfortunately, when minor problems arose, maintenance personnel were not knowledgeable in the total system, and they recommended replacement rather than repair. Most systems were replaced even though minor fixes would have solved any problems. Five units are still in operation and show savings of 50 to 70 percent over those replaced with air-to-air systems (Hildebrandt, et al, 1979).

The use of water-to-air heat pumps will have to overcome old "rule of thumb" heating and air conditioning techniques in order to be successful. The systems can be successful, but will require more attention in design and better maintenance procedures than other conventional systems. As fuel prices increase, the development and use of water source heat pumps are strengthened as an answer to rising costs. Today, several manufacturers produce water source heat pumps and projects are being studied for their future use.

Present Operation and Potential Use

Heat pump use was sporadic in the past due to poor performance of the early air source systems. Today, reliable equipment is responsible for the increased use of air-to-air heat pumps. Manufacturers are also becoming aware of the potential of water source heat pumps. Many companies are offering both types of heat pumps and some companies are being formed which only support water source systems. A partial list of manufacturers who market water source heat pumps is located in Appendix A. Water temperatures down to 40°F are acceptable in some units and others are even available that will accept freezing water.

Systems are in operation which operate from single wells, two wells, earth coils, and geothermal wells. Lakes have also been used to successfully support the systems. As long as the required water flow is maintained, just about any method of obtaining the water source can be applied.

Approximately 750,000 residential wells were drilled in 1979 which could support heat pump systems. It is estimated that there is a potential market of over 1,000,000 systems with present wells (Mahan, 1980).

Several projects have been completed to analyze the potential use of water source heat pumps. The Department of Energy has supported many of them. One study, conducted by the Argonne National Laboratory, looked at heat-pump-centered integrated community energy systems (HP-ICES). It examined the use of district heating, cooling, and hot water generation to support a series of homes or businesses (Calm, 1980). Another project just being finished by the National Water Well Association is an indepth study of ground water heat pumps. A computer simulation is used to compare costs of ground water heat pumps against electric resistance, air-to-air heat pumps, fuel oil, and natural gas. These comparisons are conducted for nine different cities in the U.S. using adjustments for costs and weather in each location (DOE, 1980).

The Texas Energy Advisory Council funded a study which analyzed ground water heat pumps with specific evaluation of their use in a home, a research lab, a school, and an office/manufacturing facility. Their findings demonstrated the economy of ground water heat pumps in the Gulf Coast area:

(1) Net energy savings are a minimum of 30% and may be as high as 50% annually

(2) Payback periods are shorter using ground water heat pumps to replace conventional electrical resistance heat than to replace gas heating. If tax rebates are considered, the payback period may be as short as three years; six years in the extreme [Hildebrandt, et al, 1979, vii].

The potential savings predicted in this study are shown in Table II.

The Department of Defense and the U.S. Navy are presently under contract to display the potential of water source heat

TABLE II

Annual Savings in Texas Case Study

Case	Annual Savings ($) (1978 dollars)	Annual Savings (%) (1978 dollars)
Residential Home	338	30
Lab/Research Buildings	2,276	50
School Building	12,122	47
Office-Warehouse	879	31
Source: Hildebrandt, et al, 1979, viii		

pumps at the Sewells Point Naval Complex, Norfolk, Virginia. The demonstration is to show both individual-unit and group-unit systems in the Willoughby housing facility (Atlantic Division, undated).

The Air Force has installed some water source heat pumps in the housing area at Patrick AFB, Florida. There are approximately 50 wells being used to support nearly 1700 homes. Included in the equipment is a heat recovery unit to augment domestic hot water generation (Peabody, 1980).

The Army-Air Force Exchange Service has recently completed a new Base Exchange/Commissary Complex at Wright-Patterson AFB, Ohio which uses water source heat pumps for heating and cooling. In the winter, the system is designed to use a maximum of 700 gallons per minute from two separate wells. In the summer, the system uses cooling towers to reject waste heat. The system is expected to achieve a COP between 5 and 6 and is expected to operate at one half the cost of a gas fired system (Cassidy, 1980; Moore, 1980; and Spurling, 1980).

Studies have been done using heat pumps in conjunction with solar collection (Andrews, Kush & Metz, 1978; Beason & Strother, 1978). Although they do work, they are not presently cost effective when compared to ground water systems by themselves. Paybacks for the solar-assisted system run as high as 32 years (Beason & Strother, 1978).

As more heat pump systems are developed and installed, more information will be available about their potential use. Even with the limited use they have had, several potential problems have become apparent.

Potential Problems and Disadvantages

Although the system has much potential, problems are possible and must be dealt with. One manufacturer, WESCORP, claims that all field problems are related to "lack of knowledge on the part of the designer, installer, and maintenance man [WESCORP, 1980, 4]." WESCORP also reports the smallest number of problems are with the equipment. Recent growth in the heat pump industry has resulted in more reliable equipment, however old "rules of thumb" used in installing and maintaining conventional systems cannot be used in heat pump systems. Since output temperatures are lower with heat pumps, more emphasis must be placed on proper insulation and correct duct sizing, pipe sizing, and equipment sizing. The heat pump is an efficient piece of equipment in theory, but if proper insulation is not used, the efficiency advantage is degraded trying to overcome excessive heating/cooling losses. Efficiency is also sacrificed if water flow or air flow is restricted and not sized properly. Larger duct systems are required because larger volumes of air are needed to accommodate the lower output temperatures (96-105°F for heating). Proper water flow must be maintained to achieve efficient thermal transfer. In addition to design problems and water disposal problems which were previously mentioned, water quality must also be considered.

Scaling, incrustation, and corrosion are additional problems which must be considered. For the majority of installations, there should not be any significant problems due to poor water quality. In certain geographical areas where water quality is poor, chemical treatment can be used to treat incrustation and scaling, while proper installation technique can reduce corrosion. The use of cupro-nickel tubing for heat exchangers has also reduced water quality problems (Hildebrandt, et al, 1979; Persons & Hart, 1980).

The amount of water needed to support water source heat pumps could cause potential problems. If consumptive use occurs, water sources could be depleted, especially if the systems are used in densely populated areas. Reinjection can help solve depletion problems but can bring in contamination and thermal problems. As stated before, the thermal problem appears to be insignificant. Transferring contaminants from one aquifer to another aquifer will have to be carefully controlled to prevent further contamination. There is very little probability that the heat pump system itself will contaminate any water source. Refrigerant leaks would not be a problem because of equipment design. Doug Bacon, manager of applied research at the National Water Well Association, lists several factors of primary importance associated with environmental problems:

- usage density, water requirements
- method of disposal of discharge water
- temperature differential of supply and discharge water
- aquifer characteristics, chemical and physical
- effectiveness of water resource management [Bacon, 1980, 9]

At the present time, public acceptance of the systems and legal problems associated with drilling supply wells and injection wells are the major areas of concern. Public acceptance will come as more systems are installed and as well drillers and heating and air conditioning contractors become familiar with the systems. The legal problems can be restrictive in certain areas, but will not pose major obstacles to implementation of heat pumps (Miller, 1980).

Probably the biggest disadvantage of the system is the initial cost. Initial costs of heat pumps are 10 to 25 percent higher than a conventional system (DOE, 1979). Adding well costs, which vary according to depth and area, increases the cost even more. The lower cost to operate the system, however, helps offset the initial cost and may make the system less expensive over its life cycle.

Overall, the problems associated with water source heat pump systems do not appear to be an obstacle to their use. What problems there are, however, are often overshadowed by the advantages of the water source heat pump system.

Advantages

Besides an apparent life cycle cost advantage which will be shown in the next chapter, water source heat pump operation is expected to have a positive impact on the environment. Air pollution would be reduced due to less fossil fuel use. Both particle and gas contamination, plus thermal pollution of the atmosphere, would be reduced. Conservation of energy would have a significant effect as a result of heat pump use (Schaetzle, et al, 1979). Overall, the positive aspects of heat pump usage would offset the minor disadvantages associated with the systems (NWWA, b).

Before a final conclusion can be drawn, however, a cost analysis must be made to show the comparison of the water source heat pump with other conventional systems of heating and cooling. This will be presented in the next chapter.

CHAPTER IV

COST ANALYSIS OF COMPARATIVE SYSTEMS

In this chapter two methods will be used to show cost comparisons. First, fuel costs will be compared to show which fuels are least expensive for a given output. This will be accomplished by using the various efficiencies listed in Chapter III, applying them to specific outputs and showing how the fuel prices relate as a result. Next, the total cost of five different systems will be compared to show how equipment, installation, maintenance, capital recovery, and operating costs are used to allow life cycle cost comparisons. Data from the DOE study will be used to show the results of these comparisons.

In making a cost comparison between different heating/cooling systems, several factors need to be considered. First, one must assume equal output requirements are being used for comparison purposes. The amount of output is not important as long as each comparison is being computed to a common basis. For example, if a 50,000 Btu load is calculated, each comparison should be accurate if the results are based on supplying the 50,000 Btu required. Once the load is established, other factors can be considered such as fuel, equipment, and installation costs. Fuel costs can be used along with equipment efficiencies to determine operating costs. Equipment and installation costs can be compared, but are only accurate for comparison when added to operating costs to determine a life cycle cost. Other factors such as maintenance costs and capital recovery costs make life cycle cost more accurate.

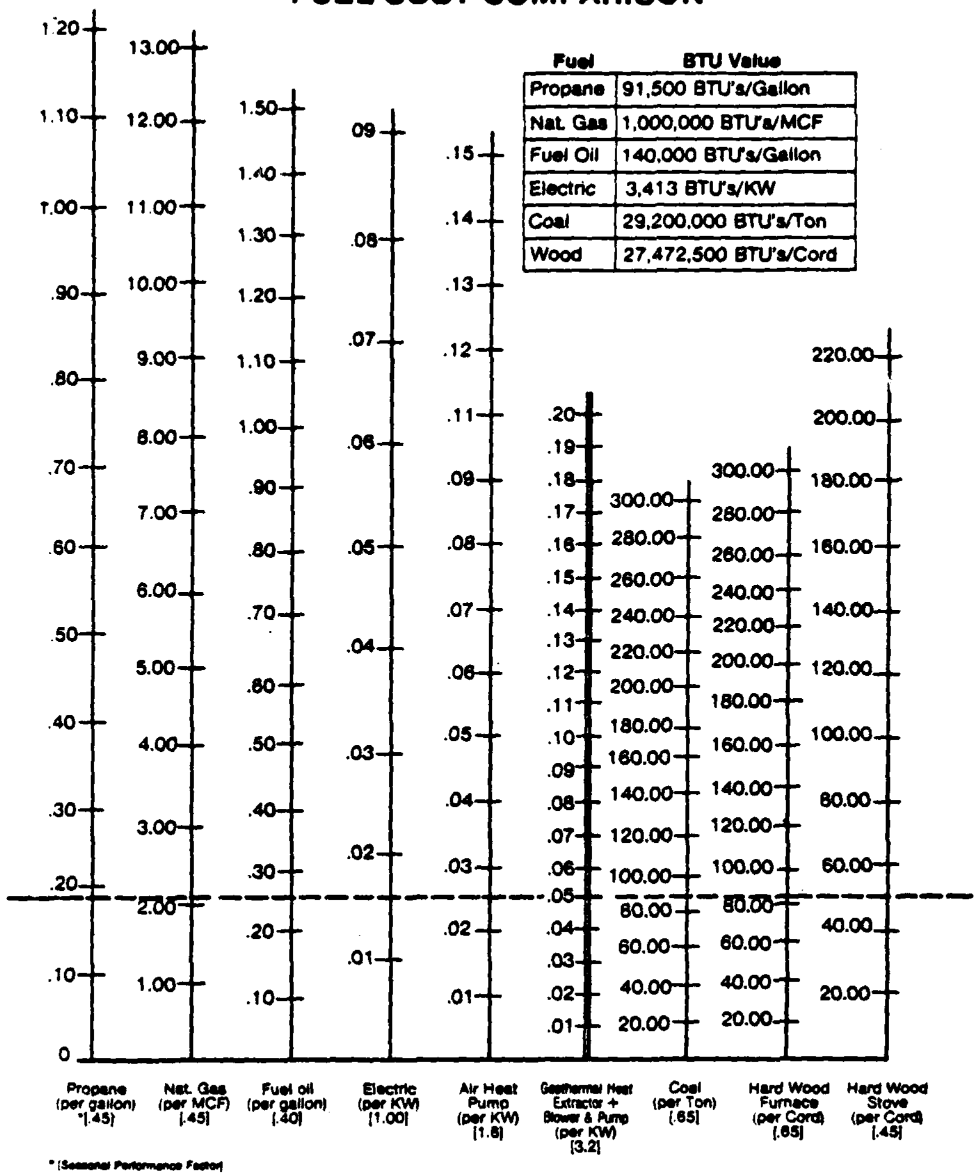
Fuel Cost Comparison

Operating costs of a heating/cooling system are mainly dependent on fuel costs used to operate the system. To be totally accurate, all fuel costs must be accounted for. For heat pumps, the total system runs on electricity, but the electricity must be measured for the compressor, the fans, and any pumping power that is used for water source heat pumps. For fossil fuel systems, the fossil fuel must be measured along with the electrical power to run the system.

Figure 14 shows a fuel cost comparison published by Thermal Energy Transfer Corporation (TETCO). It is dependent on the given efficiencies (seasonal performance factor) and accounts for primary fuel use only. Any horizontal line across the chart represents a line of equal usable Btu output for each source, based on the given Btu fuel values. This chart gives a close approximation of what fuel costs are necessary to provide equal amounts of usable energy. By having a known fuel cost, one can use this comparison to determine what the cost of other fuels could be to receive an equal output.

The following formula, derived from Figure 14 by the

FUEL COST COMPARISON



Fuel	BTU Value
Propane	91,500 BTU's/Gallon
Nat. Gas	1,000,000 BTU's/MCF
Fuel Oil	140,000 BTU's/Gallon
Electric	3,413 BTU's/KW
Coal	29,200,000 BTU's/Ton
Wood	27,472,500 BTU's/Cord

(All figures shown in dollars per unit)

Directions: Select a price for any fuel, then draw a horizontal line across the page to find the equivalent cost of any other fuel.

Example: Using a Geothermal heat extractor @ .05¢ per KW, you would have to be able to purchase fuel oil at .25¢ per gallon to be cost competitive.

Figure 14

Fuel Cost Comparison
[TETCO, 1980]

author, may also be used to obtain a relationship of fuel costs:

$$\frac{B_x E_x}{X} = \frac{Btu}{\$}$$

where

X = cost/unit of a fuel

B_x = Btu value/unit of a fuel

E_x = efficiency or COP obtained with the fuel

By equating the Btu per dollar of two fuels, one can obtain the following ratio:

$$\frac{B_x E_x}{X} = \frac{B_y E_y}{Y}$$

When real values are substituted for the constants, a relationship of one fuel cost to the other can be obtained. For example, using the Btu fuel values of Figure 14 and the average efficiencies given in Table I:

if X = cost/MCF (thousand cubic feet) of natural gas

Y = cost/kw of electricity for water source heat pump,

then

B_x = 1,000,000 Btu/MCF

E_x = .65

B_y = 3,413 Btu/kw

E_y = 3.2

and

$$\frac{1,000,000\ (.65)}{X} = \frac{3.413\ (3.2)}{Y}$$

$$\frac{650,000}{X} = \frac{10921.6}{Y}$$

$$650,000Y = 10921.6X$$

Therefore,

$$59.52Y = X$$

This shows that the price of gas/MCF can be as much as 59.52 times the cost of electricity/kw to provide the same amount of Btu. If the price of electricity is $.10/kw, then gas could not be more than $5.95/MCF to provide the same Btu at the same cost. Table III provides similar values for the other sources given in Table I when compared to water source heat pumps. Appendix B contains calculations used to arrive at the values given in Table III.

TABLE III

Fuel Cost Ratios

System (X) Vs. Water Source Heat Pump (Y)	COP	Ratio ($\frac{X}{Y}$)
Propane	.65	5.45
Fuel Oil	.60	7.69
Natural Gas	.65	59.52
Electric Resistance	.95	.30
Air Source Heat Pump	1.70	.53
Water Source Heat Pump	3.20	1.00

Figures 15, 16, and 17 show these fuel cost ratios plotted in graphical form. The graphs establish break-even lines which can be used to compare the conventional systems against the water source heat pump system. To use the graphs, one finds the current kilowatt price for the water source heat pump on the vertical axis, then moves horizontally to the

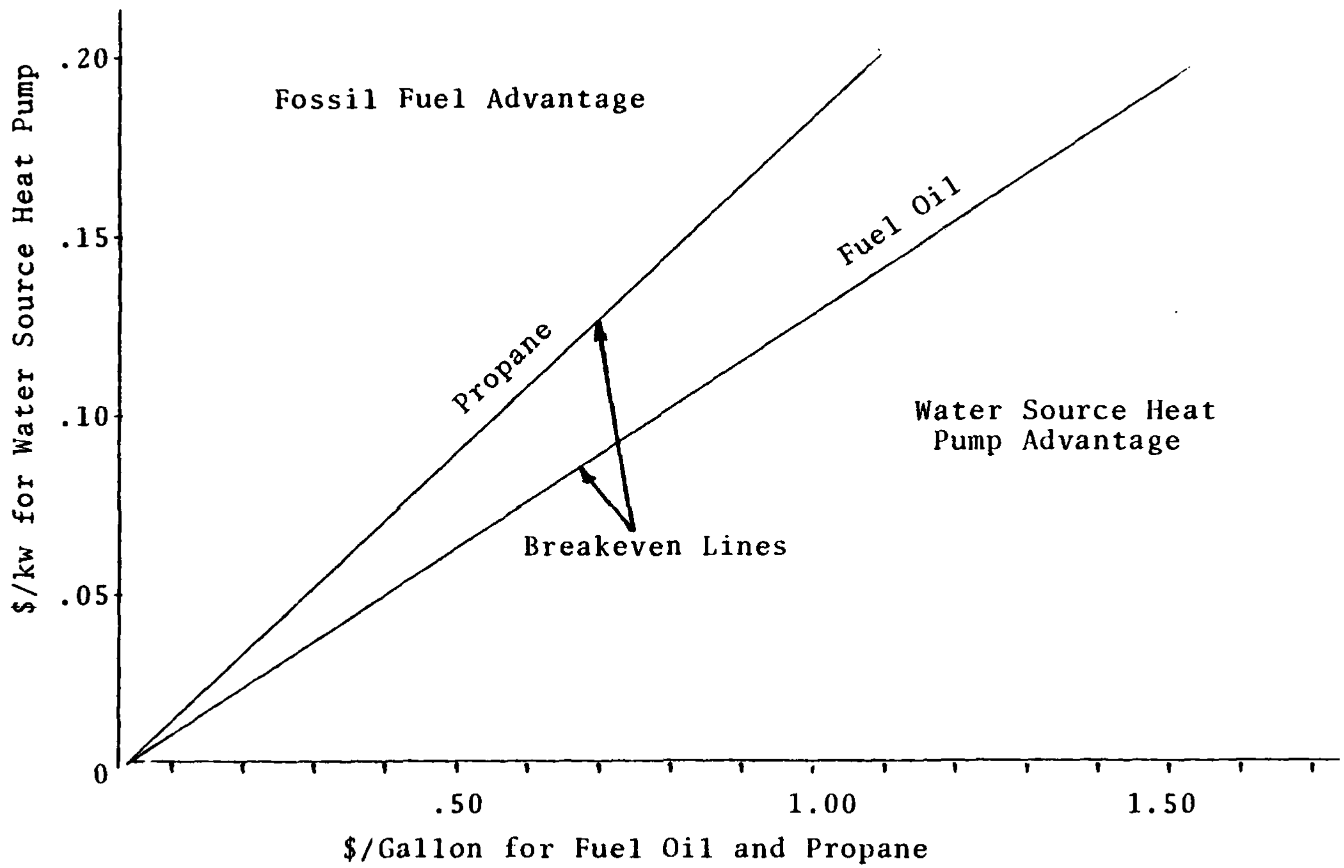


Figure 15

Propane/Fuel Oil Cost Comparisons

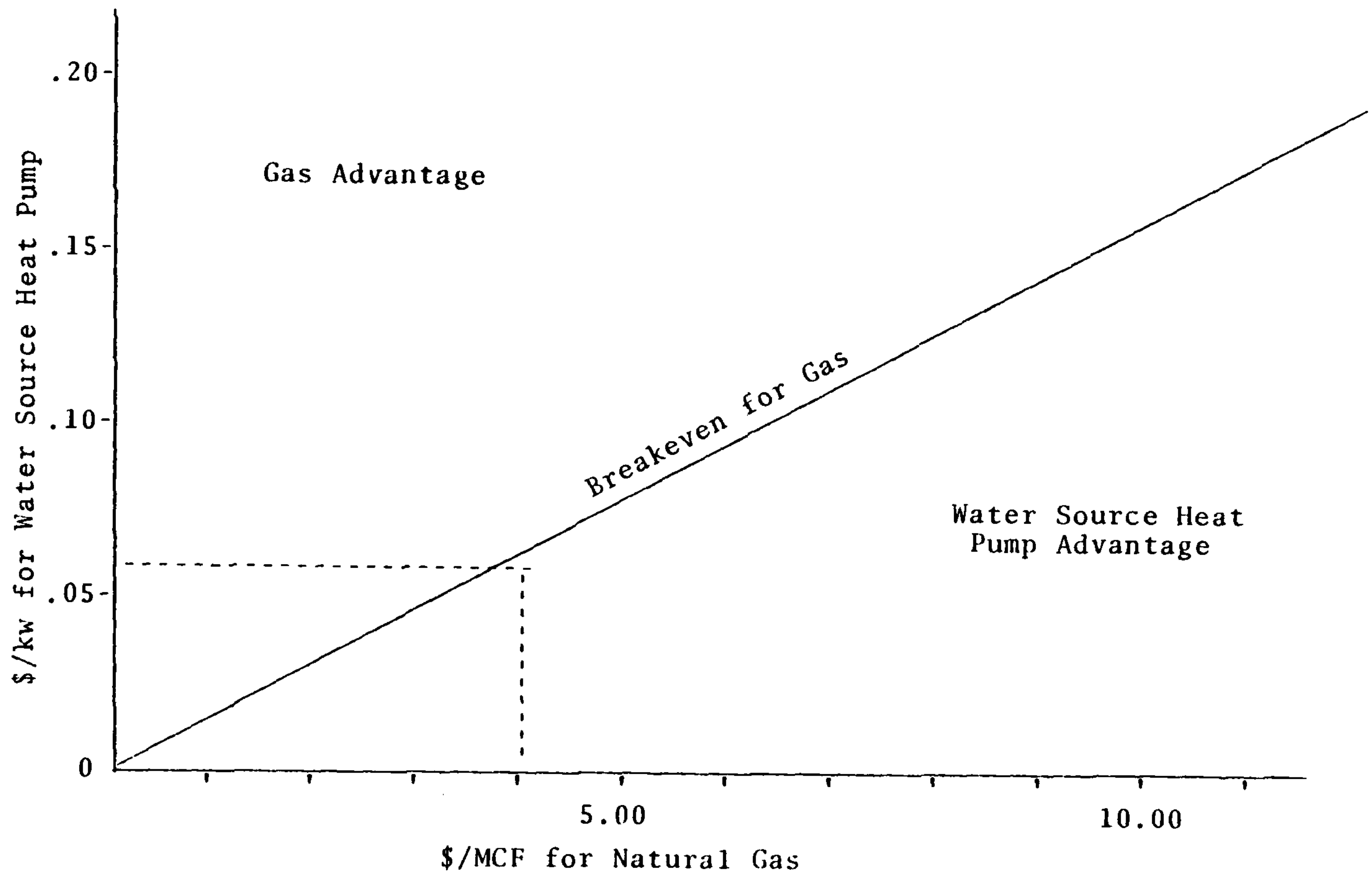


Figure 16

Natural Gas Cost Comparison

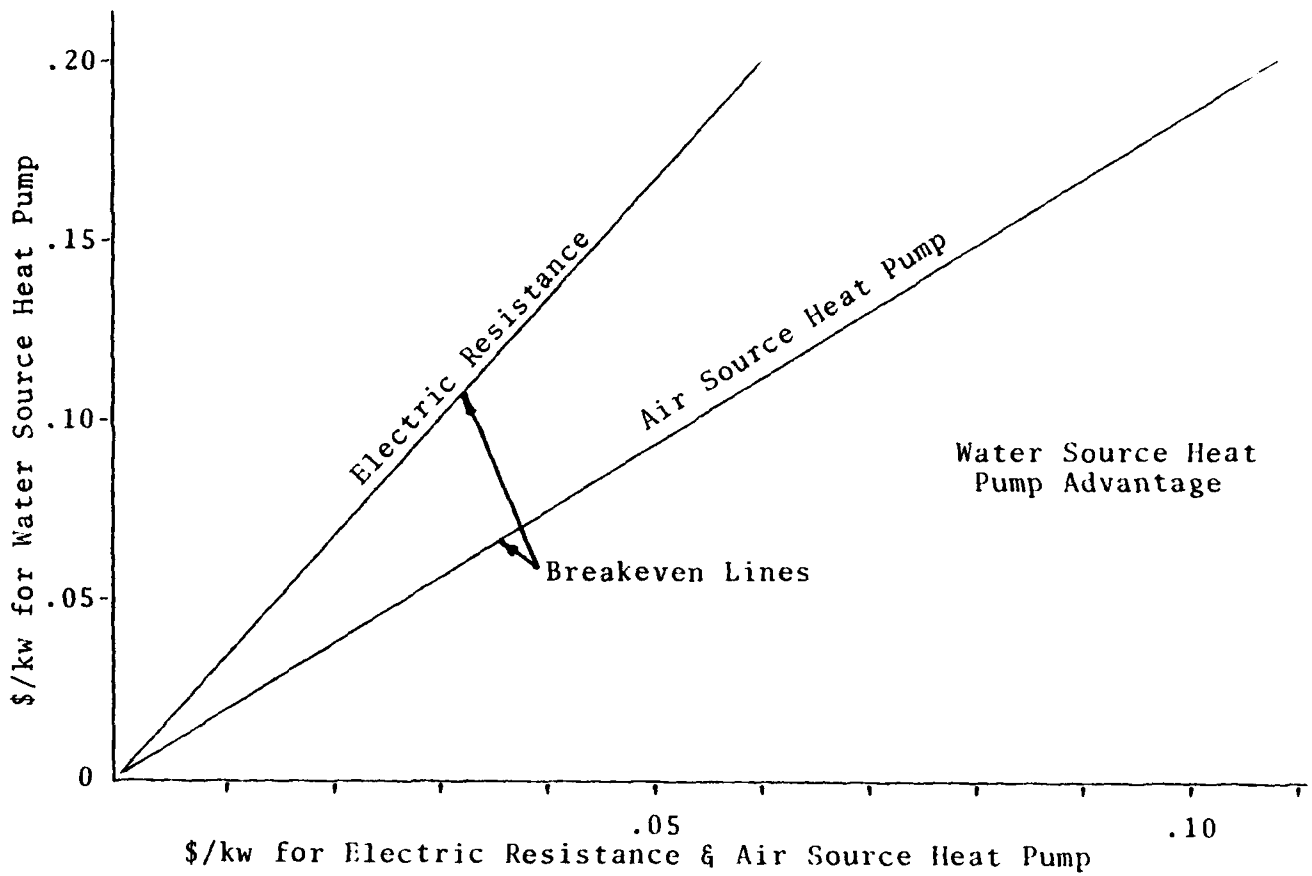


Figure 17

Electric Resistance and Air Source Heat Pump
Cost Comparisons

right to locate the current fuel price for the comparative system. If the actual price comparison falls below or to the right of the break-even line, the water source heat pump will be less expensive to operate; if the price comparison is above or left of the break-even line, the water source heat pump costs more to operate. For example, comparing kw at $.06 versus natural gas at $4.00 per MCF on Figure 16, the heat pump would cost less to operate.

It must be noted that these graphs only represent the major fuel sources for heating. Electric use for fossil systems is not accounted for and would increase the total operating cost by about 7% (Phoenix, 1980).

Any cost comparison which is made is totally dependent on the selected Btu fuel values and the given efficiencies of the systems. In comparing data from different sources of cost comparisons, one must confirm the values being used for Btu fuel values and efficiencies. It is easy to change the relationships by changing these values. For example, if the efficiency of the water source heat pump is increased, the ratios in Table III would all decrease. This would bias the comparison more towards water source heat pumps.

Other ways of presenting cost comparisons include showing either the cost of a set amount of Btu or the amount of Btu purchased for $1.00. Table IV is an example of cost per 10,000 Btu, while Table V shows an example of Btu purchased for $1.00. Both of these examples show the variances used in Btu fuel values and the variances used in efficiencies.

TABLE IV

Types of Energy Sources and Heat Content with Present Day Operating Cost

Type of Energy	Units	Gross Heat Content	Usable Heat Content	Fuel Cost	Cost 10,000 Btu
#2 Fuel Oil	Gallons	140,000 Btu/gal.	84,000 Btu/gal.*	84¢/gal.	10.0¢
Propane Gas	Gallons	91,000 Btu/gal.	54,600 Btu/gal.*	52¢/gal.	9.0¢
Natural Gas	Therms	95,000 Btu/th	57,000 Btu/th*	32¢/th	5.6¢
Electricity (Resistance)	KWH	3413 Btu/kwh	3413 Btu/kwh	3.5¢/kwh	10.0¢
Electricity (A/A heat pump standard model)	KWH	6826 Btu/kwh	6826 Btu/kwh**	3.5¢/kwh	5.1¢
Electricity (A/A heat pump high efficiency)	KWH	8533 Btu/kwh	8533 Btu/kwh***	3.5¢/kwh	4.4¢
Electricity (W/A heat pump)	KWH	10,500 Btu/kwh	10,500 Btu/kwh****	3.5¢/kwh	3.3¢
Coal	Ton	12,000 Btu/lb	5,000 Btu/lb*****	$100/ton	10.0¢

*Based on 60% efficiency
**Based on COP of 2 (200% efficiency)
***Based on COP of 2.5 (250% efficiency)
****Based on COP of 3.11 (311% efficiency)
*****Based on 38% efficiency
A/A = Air to air heat pump W/A = Water to air heat pump

Source: Mahan, 1980, 12

TABLE V

COMPARATIVE OPERATING COSTS – B.T.U.s PURCHASED PER $1.00					
TYPE UNIT	Unit Efficiency	FUEL VALUE	*FUEL COST	Usable B.T.U. Per $1.00	% Savings with SOESI
ELECTRIC RESISTANCE	100%	3413 B.T.U. Per KW	05¢ Per KW	68,260	81%
NATURAL GAS	65%	1000 B.T.U. - Per Ft^3	30¢ Per 100 Ft^3	214,000	40.3%
FUEL OIL	65%	138,000 B.T.U. - Per Gal.	80¢ Per Gal.	112,685	68.6%
PROPANE	65%	91,500 B.T.U. - Per Gal.	50¢ Per Gal.	118,950	66.8%
AIR TO AIR HEAT PUMP	Weather Zone – 5° –	*C.O.P. Ranges From 1. to 2.7 Average 1.9	05¢ Per KW	130,836	63.5%
SOESI MODEL PSS 500	100%	105,659 B.T.U. Per 5.9 KW	05¢ Per KW	358,078	

*Fuel costs may change or will vary according to geographical location. Adjustments must be made to reflect local rates.
*Air to air heat pump average C.O.P. will vary depending on weather zone.
*Cost of electric fan blowers on fossil fuel furnaces not included.
*Included as standard equipment

Source: SOESI, undated

These variances must be watched because they can distort the comparisons.

In addition to operating costs, equipment, maintenance, and capital recovery costs can be added to help determine life cycle cost, which gives a better economic comparison of various systems.

Systems Comparison

An accurate economic comparison between heating/cooling systems cannot be made by only comparing operating costs. One system may cost less to operate, but the savings may not make up the difference in equipment cost, even over many years. One good way to make an economic comparison is to use life cycle costs. Life cycle costs compare operating costs, equipment costs, estimated maintenance costs and capital recovery costs over the estimated life of the system. This gives an accurate total cost for a system which can be used to compare with total costs of other systems.

As stated in Chapter II, the National Water Well Association is completing an extensive study of ground water heat pump systems (DOE, 1980). The study contains computer simulation of life cycle cost comparisons for five different heating/cooling systems in nine different U.S. cities. The results of the study are used in this thesis because they apply to a variety of regions throughout the country. The results may indicate potential savings available to government facilities located in these regions. The five systems compared were: electric, fuel oil, and gas furnaces with central air conditioning plus air source and ground water source heat pumps with reverse cycle air conditioning. The cities that were selected are listed in Table VI along with summer and winter design temperatures, heating degree day range, ground water temperatures, and well depths.

The computer simulation enabled many variables to be controlled such as building size, heating/cooling loads, and weather. Based on operating, equipment, maintenance, and capital recovery costs, life cycle costs were computed and compared for each system in each city.

The ground water system was listed three ways, depending on the number of wells required to be drilled. One case assumed a well was present, another case showed costs to drill an injection well, and the last case allowed costs for two wells. Because of water temperature differences, either high efficiency or standard ground water heat pumps were used. In Tulsa and Birmingham both systems were acceptable.

Equipment costs are listed in Table VII and indicate installed costs. Equipment costs were obtained from Buckeye Heating and Cooling of Columbus, Ohio, and well costs were obtained from the <u>Well Drilling Cost Survey</u> done by the NWWA. Costs were indexed using the Means Handbook to allow for price differences in various regions. Columbus was used as the reference city (DOE, 1980).

The simulation of heating/cooling requirements was based on the loads listed in Table VIII. The simulation

TABLE VI

Test Cities

Test City	Summer Design Temperature °F (°C)	Winter Design Temperature °F (°C)	Representative Heating Degree Day Range	Ground Water Temperature °F (°C)	Pumping Head Ft. (m)
Atlanta	92 (33)	23 (-5)	2500 - 3500	64 (18)	25 (8)
Birmingham	94 (74)	22 (-6)	2000 - 3000	64 (18)	25 (8)
Cleveland	89 (32)	7 (-14)	6000 - 7000	54 (12)	25 (8)
Columbus	88 (31)	7 (-14)	5000 - 6000	55 (13)	50 (15)
Concord	88 (31)	-7 (-22)	7000 - 8000	48 (9)	200 (61)
Houston	94 (34)	32 (0)	500 - 2000	75 (24)	100 (30)
Philadelphia	90 (32)	15 (-9)	4000 - 5000	54 (12)	25 (8)
Seattle	79 (26)	32 (0)	4000 - 5000	51 (11)	25 (8)
Tulsa	99 (37)	16 (-9)	3000 - 4000	64 (18)	100 (30)

[DOE, 1980, 15.3]

TABLE VII

Equipment Costs

Test City	Gas System	Oil System	A-A H.P. System	Electric System	G.W.H.P. System No Well	Injection Well	Supply Well	Cost Index
Atlanta	$3310	$4510	$3370	$3230	$2650	$1400	$2070	-7.0%
Birmingham	$3190	$4340	$3240	$3110	$2340	$1500	$2130	-10.6%
Cleveland	$3820	$5200	$3880	$3720	$3560	$1500	$2270	7.0%
Columbus	$3390	$4680	$3425	$3300	$3320	$1500	$2220	0.0%
Concord	$3090	$2950	$3190	$3010	$3040	$1600	$2250	-8.8%
Houston	$3530	$4810	$3520	$3440	$2820	$2500	$3210	-0.9%
Philadelphia	$3740	$5090	$3770	$3650	$3450	$1650	$2420	4.9%
Seattle	$3740	$5090	$3515	$3650	$3450	$1800	$2550	5.0%
Tulsa	$3700	$4960	$4340	$3610	$2990	$2000	$2700	-1.9%

[DOE, 1980, 15.8-15.9]

TABLE VIII

Heating and Cooling Loads
For the Nine Test Cities

City	Seasonal (Btu X 10^{-6}) Heating	Cooling	Design (Btu x 10^{-3}) Heating	Cooling
Atlanta	33.7	24.5	40.1	34.7
Birmingham	31.7	26.4	40.8	35.9
Cleveland	73.3	9.3	52.4	31.4
Columbus	66.0	12.5	52.2	30.7
Concord	88.8	5.6	62.0	30.7
Houston	14.8	42.8	33.3	35.9
Philadelphia	55.9	13.4	46.7	32.0
Seattle	62.6	2.5	34.3	25.1
Tulsa	46.6	15.7	44.4	39.0

[DOE, 1980, 15.14]

results are listed in Appendix C and show the yearly energy consumption required for each system in each city plus the on-site and source annual coefficient of performance (ACOP).

The on-site annual coefficient of performance was calculated by dividing the total annual heating and cooling load by the total energy required to satisfy that load at the point of use. However, since electric energy generation from fossil fuels is not 100 percent efficient and is not generated on-site, a number reflecting the measure of on-site efficiency for the oil/electric and natural gas/electric systems would be somewhat meaningless. Thus, these values are not provided.

The source ACOP was calculated using a similar procedure. In this calculation, however, the electric energy required at the site was multiplied by a factor of 3 to account for efficiencies of power generation at the power plant (power plant efficiency was assumed to be 0.33) [DOE, 1980, 15.12].

The results of the simulation showed that the water source heat pump was equal to or more efficient in all cases. Both types of heat pumps were sized for the cooling loads and any heating load that needed to be supplemented was accomplished with electric resistance strips. This caused the ACOP to be lower in those cities that had higher heating loads. If the equipment had been sized for heating, the efficiencies would have been greater (DOE, 1980). In Concord, a heat-only ground water heat pump was also simulated with direct cooling. The results show an improvement in ACOP (see Appendix C, Table C-V).

In addition to the equipment costs, the energy consumption and the efficiencies, a capital recovery factor was applied. The capital recovery factor was used to determine the annualized costs of equipment, operations and maintenance, and fuel costs. The capital recovery factor was determined by the following formula:

$$CRF = \frac{(1 + d)^N \cdot d}{(1 + d)^N - 1}$$

where

CRF = capital recovery factor

d = real discount rate

N = life cycle period [DOE, 1980, 16.2]

In the DOE study, a 20-year life cycle period and a 2 percent real discount rate were used. This resulted in a capital recovery factor of .06116 (DOE, 1980).

The results of the economic evaluations are listed in Appendix D for each city. For each city and each system, the analysis shows equipment costs, annualized equipment and operation and maintenance costs, first year and annualized fuel costs, total fuel cost, total annualized cost, and total life cycle costs. Also shown are direct comparisons between the electric resistance system and the other systems. These show the differences in net benefit and the number of years for payback when compared to the electric resistance system.

The economic analysis revealed that with the proper ground water heat pump system, first year fuel costs are lower in six of the nine cities, and annualized fuel costs are lower in all nine cities. Lower life cycle costs could also be obtained with the proper system in all nine cities when a well was available. Some cities also showed lower life cycle costs when an injection well was drilled, but the gas system was very competitive. Concord (with the direct heating system) was the only city where life cycle costs showed a benefit after drilling two wells.

In Appendix E additional payback comparisons are listed. The ground water heat pump system is compared to gas, oil, and air-to-air heat pump systems. These comparisons show that the ground water heat pump system requiring no wells has a payback of less than one year when compared against all other systems. The gas system again was the best competitor.

The DOE study shows a definite advantage to using ground water heat pumps; however, only part of the true energy picture was presented. Domestic hot water generation accounts for 18 to 27 percent more energy consumption in the nine cities (DOE, 1980). Without showing the effects of this energy load, the comparison is rather shallow. The author was able to obtain additional raw data from the National Water Well Association to calculate the added cost for hot water generation.

In the additional data, hot water generation was obtained with an electric resistance heater for the electric resistance, air source heat pump and oil systems. Gas was used in the gas system, and a desuperheater in the refrigerant loop was used in the water source heat pump system. Table IX shows the additional energy consumption for each system; Table X indicates first year energy prices; and Table XI shows the additional cost for first year fuel costs. Table XII shows the total first year fuel costs with hot water generation added for each system. The costs were computed by adding values from Appendix D and Table XI.

When the hot water generation was added to the costs, the system comparisons changed. Gas was the lowest cost fuel for total first year costs in all cities except Seattle. The desuperheater, however, was less expensive than electric resistance heaters in all cities. Annualized energy prices were not available, so a comparison of annualized fuel costs could not be made. An annualized comparison could indicate changes in the comparison due to relative price changes

TABLE IX

Additional Yearly Energy Consumption/ Hot Water Generation (Btu X 10^{-6})

City	Water Heaters Electric Resistance	Gas	Desuperheater
Atlanta*	20.73	28.40	13.45
Birmingham*	20.79	28.48	13.11
Birmingham	20.79	28.48	13.05
Cleveland	20.90	28.63	14.26
Columbus	20.87	28.59	14.32
Concord	20.94	28.68	16.84
Houston*	20.59	28.21	11.32
Philadelphia	20.84	28.55	14.23
Seattle	21.02	28.79	16.29
Tulsa*	20.79	28.48	14.11
Tulsa	20.79	28.48	14.02

*Standard efficiency water source heat pump
NOTE: Values obtained from NWWA

between fuel sources. For instance, if the price of gas increases significantly in the future, the water source heat pump could look more favorable as long as electric costs did not rise faster. Also, total life cycle costs were not available which would provide the best comparison.

The DOE study is not the only analysis that supports the cost benefits of water source heat pumps. A study done by the Argonne National Laboratory shows "annual cost savings

TABLE X

First Year Energy Prices

(in 1979 Dollars per 10^6 Btu)

City	Electric	Gas
Atlanta	11.63	2.74
Birmingham	11.63	2.74
Cleveland	14.08	2.77
Columbus	14.08	2.77
Concord	17.41	4.53
Houston	12.91	2.85
Philadelphia	14.86	3.22
Seattle	6.03	3.88
Tulsa	12.91	2.85

NOTE: Values obtained from NWWA

of 13 to 30 percent over the next best alternative [Schaetzle, et al, 1979, 71]." Another study done for the Texas Energy Advisory Council showed yearly savings from 30 to 50 percent when water source heat pumps were used (Hildebrandt, et al, 1979).

The cost advantages described in this thesis can only be viewed as an indication of the potential savings which may be available if water-to-air heat pumps are used in government facilities. Each potential application of a heating/cooling system is very site specific and depends on many variables. A general statement, that one specific system

TABLE XI

Additional First Year Fuel Costs/

Hot Water Generation (in 1979 Dollars)

City	Water Heaters Electric Resistance	Gas	Desuperheater
Atlanta*	241	78	156
Birmingham*	242	78	152
Birmingham	242	78	152
Cleveland	294	79	201
Columbus	294	79	202
Concord	365	130	293
Houston*	266	80	146
Philadelphia	310	92	211
Seattle	127	112	98
Tulsa*	268	81	182
Tulsa	268	81	181

*Standard efficiency water source heat pump
NOTE: computed from Tables IX and X

will always be best, cannot be made because of these variables. Fuel and equipment costs are constantly changing and have a significant impact on the results of any comparative analysis. A decision to install a specific system depends on the local conditions which exist at the time the decision is made.

TABLE XII

Total First Year Fuel Costs/Hot Water Generation

City	Electric Resistance	Air Heat Pump	Oil	Natural Gas	Water Heat Pump
Atlanta*	764	556	614	361	407
Birmingham*	753	561	611	363	403
Birmingham	756	564	614	366	391
Cleveland	1397	950	863	483	618
Columbus	1312	908	832	469	612
Concord	2207	1547	1076	822	1181
Houston*	741	624	639	418	512
Philadelphia	1267	842	821	487	596
Seattle	497	301	549	547	236
Tulsa*	1033	711	708	406	546
Tulsa	1033	711	708	406	518

*Standard efficiency water source heat pump

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

The objective of this thesis was to provide government managers with information about water source heat pump systems and to examine economic comparisons with conventional systems. By achieving this objective, one should be able to determine if water-to-air heat pumps can provide an economically effective answer to reducing energy consumption. The author has found that water source heat pumps do offer a potential opportunity to save energy. Savings, shown in Table II (page 40), can occur in residential homes plus various general purpose buildings, as was demonstrated in the study (Calm, 1980) completed for the Texas Energy Advisory Council. The results of this study could be directly comparable to results the federal government could expect to receive in similar government structures located in the same geographical area. Water source heat pumps show a definite economic advantage over electric resistance systems and over air source heat pumps, as was shown in the economic comparisons in Appendix D. The best advantage is obtained when a water source or well is already present. The 1980 DOE study shows how the water source heat pump systems can compare across various regions of the U.S. with favorable results in the selected geographical areas. Provided the correct system is selected for each location, even northern locations show a potential advantage of using water source heat pumps. Conventional systems, in some cases, are very competitive with the water source heat pumps; however, changing energy prices can generate different results.

Space heating and cooling account for approximately 21 percent of the total energy used in the U.S. Water source heat pumps have been shown to be highly efficient and provide a savings of 30-50 percent in energy use. This equates to a potential 10 percent savings in total U.S. energy use. By increasing the use of water source heat pumps, a reduction of fossil fuel use can be generated.

An important aspect about the situation is that the technology exists to obtain these savings today. Extensive research and development does not have to be completed in order to achieve these energy savings. The process simply transfers heat from one location to another location using proven technology which has been in use for years. High efficiencies are achieved through transferring heat rather than generating heat using fossil fuels or electric resistance.

Problems of water sources and disposal are not considered to be unsolveable; however, legal aspects in some states, environmental impacts, and water quality problems in some geographical areas must be dealt with. In those few areas that will not support well systems, closed loop systems can be used to support the heat pump systems.

Water source heat pumps can reduce energy consumption and can provide a very impressive opportunity to reduce heating and cooling costs. Water source heat pumps can also provide savings in generating hot water when compared to conventional electric resistance heaters.

Based on the apparent economic advantages of the water source heat pump system and the results of the research completed in this thesis, several recommendations can be made.

First, information concerning the use of water source heat pumps should be provided to government civil engineers. Since these systems show a definite advantage over electric resistance and, in some cases, air source heat pumps, civil engineers should be aware of the available equipment that can provide energy savings.

Assuming that civil engineers receive information about water source heat pumps, these systems should be considered for all new government building construction. A site-specific analysis would be necessary to determine if the appropriate variables (fuel costs, water sources, environmental considerations, legal implications, and heating/cooling loads) warrant the use of the water source systems.

Water source systems should also be considered when existing systems need replacement. Replacing old, worn-out heating/cooling systems with water source systems would provide another opportunity to reduce energy consumption. Reduced operating costs could offset any cost differences between possible replacement systems.

Additional research should be accomplished to provide more information about potential applications. Since many of the completed studies have been simulations, actual applications should be accomplished to test predicted results. Studies on well spacing are needed, plus more data on selecting appropriate systems for various heating/cooling loads should be made.

Finally, studies showing specific areas of application within the government would further define potential savings. For example, showing the potential use of water source heat pumps at specific military installations located in northern states could indicate potential savings. A specific application could be considered for use at the new MX bases being planned by the U.S. Air Force.

Water source heat pump systems have been shown to be more energy efficient than conventional heating/cooling systems. The technology is present to allow widespread use of these systems in appropriate geographical areas with potential savings of 10 percent of the total annual U.S. energy consumption.

APPENDIX A

HEAT PUMP MANUFACTURERS

Company Name and Address

(NOTE: Courtesy of National Water Well Association)

Air Conditioning Corp.
P.O. Box 6225
Greensboro, NC 27405

American Air Filter
215 Central Ave.
Louisville, KY 40277

American Solar King Corp.
6801 New McGregor Hwy.
Waco, TX 76710

Carrier Air Condition
Div. of Carrier Corp.
Carrier Parkway
Syracuse, NY 13201

Command Aire Corp.
P.O. Box 7916
Waco, TX 76710

Dunham-Bush, Inc.
175 South Street
West Hartford, CT 06110

Florida Heat Pump Corp.
610 Southeast 12th Ave.
Pompano Beach, FL 33060

Friedrich
4200 N. Pan American Expressway
P.O. Box 1540
San Antonio, TX 78295

Friedrich
2000 West Commercial Blvd.
Fort Lauderdale, FL 22209

Gervais Equipment
9295 Fargo Road
Stafford, NY 14143

Heat Controller, Inc.
Losey at Wellworth
Jackson, MI 49203

Heat Exchanger, Inc.
8100 N. Monticello Ave.
Skokie, IL 60076

Mammoth Division
Lear Siegler, Inc.
Holland Plant
941 E. 7th St.
Holland, MI 49423

McQuay Group
McQuay-Perfex, Inc.
13600 Industrial Park Blvd.
P.O. Box 1551
Minneapolis, MN 55440

Mueller Climatrol Corp.
Woodbridge Ave.
Edison, NJ 08817

NESCO, Inc.
P.O. Box 280
Monroe, NC 28110

Phoenix Enviro-Temp
651 Vernon Way
El Cajon, CA 92020

Singer Co., Climate Control Div.
401 Randolph St.
Red Bud, IL 62278

Solar Energy Resources Corp.
10639 Southwest 185th Terrace
Miami, FL 33157

Spectrum Solar Systems Corp.
11615 Saylor Road
Pickerington, OH 43147

International Energy Conservation
Systems, Inc.
1775 Central Florida Parkway
Regency Industrial Park
Orlando, FL 32809

Tetco Heat Extractor
5515 Old Three C Highway
Westerville, OH 43081

Vilter Manufacturing Corp.
2217 South First Street
Milwaukee, WI 53207

Weatherking, Inc.
4501 East Colonial Drive
Box 20434
Orlando, FL 32814

WESCORP, Inc.
15 Stevens Street
Andover, MA 01810

Vanguard Energy Systems
9133 Chesapeake Dr.
San Diego, CA 92123

The Whalen Co.
4030 Benson Ave.
Baltimore, MD 21227

Wilcox Manufacturing Corp.
13375 U.S. 19 North At 62nd St.
P.O. Box 455
Pinellas Park, FL 33565

York, Div. of Borg-Warner Corp.
P.O. Box 1592
York, PA 17405

Northrup, Inc.
302 Nichols Dr.
Hutchins, TX 75141

Calmac Mfg. Corp.
150 Brunt St.
Englewood, NJ 07631

APPENDIX B

FUEL COST RATIOS

Water Source Vs Propane

$$\frac{B_x E_x}{X} = \frac{B_y E_y}{Y}$$

if X = cost/gallon for propane

Y = cost/kw for water source heat pump

then, B_x = 91,500 Btu/gallon

B_y = 3413 Btu/kw

E_x = .65

E_y = 3.2

and

$$\frac{91{,}500\ (.65)}{X} = \frac{3413\ (3.2)}{Y}$$

$$59475Y = 10921.6X$$

$$5.45Y = X$$

Water Source Vs Fuel Oil

$$\frac{B_x E_x}{X} = \frac{B_y E_y}{Y}$$

if X = cost/gallon for fuel oil

Y = cost/kw for water source heat pump

then, B_x = 140,000 Btu/gallon

B_y = 3413 Btu/kw

E_x = .60

E_y = 3.2

and

$$\frac{140{,}000\ (.60)}{X} = \frac{3413\ (3.2)}{Y}$$

$$84{,}000Y = 10921.6X$$

$$7.69Y = X$$

Water Source Vs Electric Resistance

$$\frac{B_x E_x}{X} = \frac{B_y E_y}{Y}$$

if X = cost/kw for electric resistance

Y = cost/kw for water source heat pump

then, B_x, B_y = 3413 Btu/kw

E_x = .95

E_y = 3.2

and

$$\frac{3413\ (.95)}{X} = \frac{3413\ (3.2)}{Y}$$

$$3242.4Y = 10921.6X$$

$$.297Y = X$$

Water Source Vs Air Source

$$\frac{B_x E_x}{X} = \frac{B_y E_y}{Y}$$

if X = cost/kw for air source heat pump

Y = cost/kw for water source heat pump

then B_x, B_y = 3413 Btu/kw

E_x = 1.7

E_y = 3.2

and

$$\frac{3413\ (1.7)}{X} = \frac{3413\ (3.2)}{Y}$$

$$5802.1Y = 10921.6X$$

$$.53Y = X$$

APPENDIX C

YEARLY ENERGY CONSUMPTIONS

TABLE C-I

Yearly Energy Consumption - Atlanta

HVAC System Heating/Cooling Plant	($Btu \times 10^{-6}$) Electric	Fossil	On-Site ACOP	Source ACOP
Natural Gas/Electric	11.6	52.7		.7
Oil/Electric	11.6	46.1		.7
Air-to-Air Heat Pump	26.7		2.2	.7
Electric/Electric	44.4		1.3	.4
Ground Water Heat Pump Standard	21.3		2.7	.9

TABLE C-II

Yearly Energy Consumption - Birmingham

HVAC System Heating/Cooling Plant	($Btu \times 10^{-6}$) Electric	Fossil	On-Site ACOP	Source ACOP
Natural Gas/Electric	12.5	49.7		.7
Oil/Electric	12.5	43.4		.7
Air-to-Air Heat Pump	27.0		2.2	.7
Electric/Electric	43.3		1.3	.5
Ground Water Heat Pump				
Standard	21.2		2.7	.9
High Efficiency	20.2		2.9	1.0

TABLE C-III

Yearly Energy Consumption - Cleveland

HVAC System Heating/Cooling Plant	($Btu \times 10^{-6}$) Electric	Fossil	On-Site ACOP	Source ACOP
Natural Gas/Electric	5.7	114.5		.6
Oil/Electric	5.7	100.9		.7
Air-to-Air Heat Pump	46.0		1.8	.6
Electric/Electric	77.4		1.1	.4
Ground Water Heat Pump High Efficiency	29.3		2.8	.9

TABLE C-IV

Yearly Energy Consumption - Columbus

HVAC System Heating/Cooling Plant	(Btu x 10^{-6}) Electric	Fossil	On-Site ACOP	Source ACOP
Natural Gas/ Electric	7.0	103.1		.6
Oil/Electric	7.0	90.8		.7
Air-to-Air Heat Pump	43.1		1.8	.6
Electric/Electric	71.5		1.1	.4
Ground Water Heat Pump High Efficiency	28.8		2.7	.9

AD-A093 179 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 13/1
AN ANALYSIS OF WATER-TO-AIR HEAT PUMP SYSTEMS FOR USE IN GOVERN--ETC(U)
SEP 80 R G FRETZS
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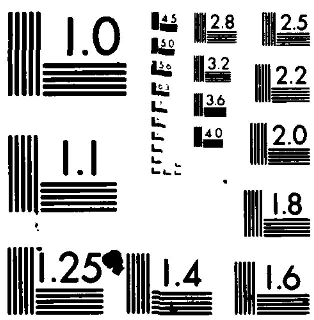

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE C-V

Yearly Energy Consumption - Concord

HVAC System Heating/Cooling Plant	(Btu x 10^{-6}) Electric	Fossil	On-Site ACOP	Source ACOP
Natural Gas/Electric	4.2	139.0		.6
Oil/Electric	4.2	122.6		.7
Air-to-Air Heat Pump	58.5		1.6	.5
Electric/Electric	91.2		1.0	.3
Ground Water Heat Pump				
High Efficiency	44.0		2.2	.7
Heat-Only/Direct Cooling	29.6		3.2	1.1

TABLE C-VI

Yearly Energy Consumption - Houston

HVAC System Heating/Cooling Plant	($Btu \times 10^{-6}$) Electric	Fossil	On-Site ACOP	Source ACOP
Natural Gas/ Electric	19.0	23.5		.7
Oil/Electric	19.0	20.1		.8
Air-to-Air Heat Pump	25.1		2.3	.8
Electric/Electric	33.3		1.7	.6
Ground Water Heat Pump				
Standard	25.6		2.3	.8
High Efficiency	23.0		2.5	.8

TABLE C-VII

Yearly Energy Consumption - Philadelphia

HVAC System Heating/Cooling Plant	($Btu \times 10^{-6}$) Electric	Fossil	On-Site ACOP	Source ACOP
Natural Gas/Electric	7.3	87.3		.6
Oil/Electric	7.3	76.8		.7
Air-to-Air Heat Pump	34.4		2.0	.7
Electric/Electric	61.8		1.1	.4
Ground Water Heat Pump High Efficiency	24.8		2.8	.9

TABLE C-VIII

Yearly Energy Consumption - Seattle

HVAC System Heating/Cooling Plant	($Btu \times 10^{-6}$) Electric	Fossil	On-Site ACOP	Source ACOP
Natural Gas/Electric	3.2	96.7		.6
Oil/Electric	3.2	85.2		.7
Air-to-Air Heat Pump	29.9		2.2	.7
Electric/Electric	63.7		1.0	.3
Ground Water Heat Pump High Efficiency	23.8		2.7	.9

TABLE C-IX

Yearly Energy Consumption - Tulsa

HVAC System Heating/Cooling Plant	($Btu \times 10^{-6}$) Electric	Fossil	On-Site ACOP	Source ACOP
Natural Gas/Electric	8.2	72.8		.6
Oil/Electric	8.2	64.0		.7
Air-to-Air Heat Pump	31.1		2.0	.7
Electric/Electric	53.6		1.2	.4
Ground Water Heat Pump				
Standard	25.5		2.4	.8
High Efficiency	23.6		2.6	.9

APPENDIX D

ECONOMIC EVALUATIONS

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN ATLANTA, GEORGIA

ECONOMIC ANALYSIS PARAMETERS
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BEGINNING YR. OF SIM	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)
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ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3230.	3370.	4510.	3310.	2650.	4050.	5724.
ANNUALIZED - EQUIP.	198.	206.	276.	202.	162.	249.	352.
OP. & MAINT.	32.	34.	45.	33.	27.	41.	59.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	146.	0.	0.	0.
HEATING OIL	0.	0.	236.	0.	0.	0.	0.
ELECTRICITY	523.	315.	137.	137.	251.	251.	251.
TOTAL FUEL	523.	315.	373.	283.	251.	251.	251.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	212.	0.	0.	0.
HEATING OIL	0.	0.	352.	0.	0.	0.	0.
ELECTRICITY	607.	366.	159.	159.	291.	291.	291.
TOTAL ANNUALIZED FUEL	607.	366.	511.	371.	291.	291.	291.
TOTAL FUEL COST	9923.	5977.	8355.	6061.	4765.	4765.	4765.
TOTAL ANNUALIZED COST	837.	605.	832.	606.	480.	580.	713.
TOTAL LIFE CYCLE COST	13681.	9898.	13602.	9912.	7848.	9477.	11657.
PRESENT WORTH OF-TOTAL NET BENEFIT	0.	-3783.	-79.	-3769.	-5833.	-4204.	-2024.
FIRST YEAR-							
DELTA EQUIP COST	0.	140.	1280.	80.	-580.	820.	2694.
DELTA FUEL & OP COST	0.	-207.	-137.	-239.	-278.	-264.	-245.
PAYBACK (YRS)	(-)	1.00	9.33	1.00	1.00	3.11	10.99

* - INDICATES STANDARD MODEL GROUND WATER HEAT PUMP

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN BIRMINGHAM, ALABAMA

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3110.	3240.	4340.	3190.	2340.	3840.	5765.
ANNUALIZED - EQUIP.	190.	198.	265.	195.	143.	235.	353.
OP. & MAINT.	31.	32.	43.	32.	23.	38.	58.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	138.	0.	0.	0.
HEATING OIL	0.	0.	222.	0.	0.	0.	0.
ELECTRICITY	511.	319.	147.	147.	251.	251.	251.
TOTAL FUEL	511.	319.	369.	285.	251.	251.	251.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	199.	0.	0.	0.
HEATING OIL	0.	0.	331.	0.	0.	0.	0.
ELECTRICITY	592.	370.	171.	171.	290.	290.	290.
TOTAL ANNUALIZED FUEL	592.	370.	502.	370.	290.	290.	290.
TOTAL FUEL COST	9681.	6048.	8205.	6049.	4750.	4750.	4750.
TOTAL ANNUALIZED COST	813.	600.	811.	597.	457.	564.	701.
TOTAL LIFE CYCLE COST	13300.	9818.	13255.	9761.	7473.	9218.	11457.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-3482.	-45.	-3539.	-5827.	-4082.	-1842.
FIRST YEAR- DELTA EQUIP COST	0.	130.	1230.	80.	-770.	730.	2655.
DELTA FUEL & OP COST	0.	-191.	-130.	-225.	-268.	-253.	-233.
PAYBACK (YRS)	(-)	1.00	9.48	1.00	1.00	2.89	11.37

* - INDICATES STANDARD MODEL GROUND WATER HEAT PUMP

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3110.	3240.	4340.	3190.	2780.	4280.	6205.
ANNUALIZED - EQUIP.	190.	198.	265.	195.	170.	262.	379.
OP. & MAINT.	31.	32.	43.	32.	28.	43.	62.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	138.	0.	0.	0.
HEATING OIL	0.	0.	222.	0.	0.	0.	0.
ELECTRICITY	514.	322.	150.	150.	239.	239.	239.
TOTAL FUEL	514.	322.	372.	288.	239.	239.	239.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	199.	0.	0.	0.
HEATING OIL	0.	0.	331.	0.	0.	0.	0.
ELECTRICITY	595.	373.	174.	174.	277.	277.	277.
TOTAL ANNUALIZED FUEL	595.	373.	505.	373.	277.	277.	277.
TOTAL FUEL COST	9737.	6104.	8260.	6104.	4523.	4523.	4523.
TOTAL ANNUALIZED COST	817.	604.	814.	600.	474.	581.	718.
TOTAL LIFE CYCLE COST	13356.	9874.	13310.	9816.	7758.	9503.	11742.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-3482.	-46.	-3540.	-5598.	-3853.	-1613.
FIRST YEAR- DELTA EQUIP COST	0.	130.	1230.	80.	-330.	1170.	3095.
DELTA FUEL & OP COST	0.	-191.	-130.	-225.	-278.	-263.	-244.
PAYBACK (YRS)	(-)	1.00	9.48	1.00	1.00	4.44	12.68

* - INDICATES HIGH EFFICIENCY MODEL GROUND WATER HEAT PUMP

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3720.	3880.	5200.	3820.	3560.	5060.	7117.
ANNUALIZED - EQUIP.	228.	237.	318.	234.	218.	309.	435.
OP. & MAINT.	37.	39.	52.	38.	36.	51.	71.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	323.	0.	0.	0.
HEATING OIL	0.	0.	488.	0.	0.	0.	0.
ELECTRICITY	1103.	656.	81.	81.	417.	417.	417.
TOTAL FUEL	1103.	656.	569.	404.	417.	417.	417.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	468.	0.	0.	0.
HEATING OIL	0.	0.	713.	0.	0.	0.	0.
ELECTRICITY	1270.	755.	94.	94.	481.	481.	481.
TOTAL ANNUALIZED FUEL	1270.	755.	807.	562.	481.	481.	481.
TOTAL FUEL COST	20765.	12352.	13189.	9191.	7859.	7859.	7859.
TOTAL ANNUALIZED COST	1535.	1031.	1177.	834.	734.	841.	987.
TOTAL LIFE CYCLE COST	25093.	16866.	19239.	13636.	12001.	13746.	16139.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-8227.	-5854.	-11458.	-13092.	-11347.	-8954.
FIRST YEAR- DELTA EQUIP COST	0.	160.	1480.	100.	-160.	1340.	3397.
DELTA FUEL & OP COST	0.	-445.	-519.	-698.	-688.	-673.	-652.
PAYBACK (YRS)	(-)	1.00	2.85	1.00	1.00	1.99	5.21

* - INDICATES HIGH EFFICIENCY MODEL GROUND WATER HEAT PUMP

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN COLUMBUS, OHIO

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF LCC	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3300.	3425.	4680.	3390.	3320.	4820.	6829.
ANNUALIZED - EQUIP.	202.	209.	286.	207.	203.	295.	418.
OP. & MAINT.	33.	34.	47.	34.	33.	48.	68.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	291.	0.	0.	0.
HEATING OIL	0.	0.	439.	0.	0.	0.	0.
ELECTRICITY	1018.	614.	99.	99.	410.	410.	410.
TOTAL FUEL	1018.	614.	538.	390.	410.	410.	410.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	422.	0.	0.	0.
HEATING OIL	0.	0.	641.	0.	0.	0.	0.
ELECTRICITY	1173.	707.	114.	114.	473.	473.	473.
TOTAL ANNUALIZED FUEL	1173.	707.	756.	536.	473.	473.	473.
TOTAL FUEL COST	19178.	11566.	12360.	8767.	7731.	7731.	7731.
TOTAL ANNUALIZED COST	1408.	951.	1089.	777.	709.	816.	959.
TOTAL LIFE CYCLE COST	23018.	15551.	17805.	12711.	11594.	13339.	15677.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-7467.	-5212.	-10306.	-11424.	-9678.	-7340.
FIRST YEAR- DELTA EQUIP COST	0.	125.	1380.	90.	20.	1520.	3529.
DELTA FUEL & OP COST	0.	-403.	-466.	-627.	-608.	-593.	-573.
PAYBACK (YRS)	(-)	1.00	2.96	1.00	1.00	2.56	6.16

* - INDICATES HIGH EFFICIENCY MODEL GROUND WATER HEAT PUMP

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN CONCORD, NEW HAMPSHIRE

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3010.	3190.	4270.	3090.	2820.	4420.	6452.
ANNUALIZED - EQUIP.	184.	195.	261.	189.	172.	270.	395.
OP. & MAINT.	30.	32.	43.	31.	28.	44.	65.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	608.	0.	0.	0.
HEATING OIL	0.	0.	627.	0.	0.	0.	0.
ELECTRICITY	1842.	1182.	84.	84.	888.	888.	888.
TOTAL FUEL	1842.	1182.	711.	692.	888.	888.	888.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	809.	0.	0.	0.
HEATING OIL	0.	0.	895.	0.	0.	0.	0.
ELECTRICITY	1943.	1247.	89.	89.	937.	937.	937.
TOTAL ANNUALIZED FUEL	1943.	1247.	984.	898.	937.	937.	937.
TOTAL FUEL COST	31774.	20387.	16088.	14679.	15324.	15324.	15324.
TOTAL ANNUALIZED COST	2157.	1474.	1288.	1118.	1138.	1252.	1396.
TOTAL LIFE CYCLE COST	35276.	24099.	21056.	18274.	18605.	20467.	22831.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-11178.	-14220.	-17002.	-16671.	-14809.	-12445.
FIRST YEAR- DELTA EQUIP COST	0.	180.	1260.	80.	-190.	1410.	3442.
DELTA FUEL & OP COST	0.	-658.	-1118.	-1149.	-956.	-940.	-920.
PAYBACK (YRS)	(-)	1.00	1.13	1.00	1.00	1.50	3.74

* - INDICATES HIGH EFFICIENCY MODEL GROUND WATER HEAT PUMP

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN CONCORD, NEW HAMPSHIRE

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3010.	3190.	4270.	3090.	3040.	4640.	6672.
ANNUALIZED - EQUIP.	184.	195.	261.	189.	186.	284.	408.
OP. & MAINT.	30.	32.	43.	31.	30.	46.	67.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	608.	0.	0.	0.
HEATING OIL	0.	0.	627.	0.	0.	0.	0.
ELECTRICITY	1342.	1182.	84.	84.	598.	598.	598.
TOTAL FUEL	1342.	1182.	711.	692.	598.	598.	598.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	809.	0.	0.	0.
HEATING OIL	0.	0.	895.	0.	0.	0.	0.
ELECTRICITY	1943.	1247.	89.	89.	630.	630.	630.
TOTAL ANNUALIZED FUEL	1943.	1247.	984.	898.	630.	630.	630.
TOTAL FUEL COST	31774.	20387.	16088.	14679.	10309.	10309.	10309.
TOTAL ANNUALIZED COST	2157.	1474.	1288.	1118.	847.	961.	1105.
TOTAL LIFE CYCLE COST	35276.	24099.	21056.	18274.	13846.	15708.	18072.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-11178.	-14220.	-17002.	-21430.	-19568.	-17204.
FIRST YEAR- DELTA EQUIP COST	0.	180.	1260.	80.	30.	1630.	3662.
DELTA FUEL & OP COST	0.	-658.	-1118.	-1149.	-1244.	-1228.	-1207.
PAYBACK (YRS)	(-)	1.00	1.13	1.00	1.00	1.33	3.03

* - INDICATES HIGH EFFICIENCY MODEL GROUND WATER HEAT PUMP

Direct Cooling

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN HOUSTON, TEXAS

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3440.	3520.	4810.	3530.	2820.	5320.	8207.
ANNUALIZED - EQUIP.	210.	215.	294.	216.	172.	325.	502.
OP. & MAINT.	34.	35.	48.	35.	28.	53.	82.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	67.	0.	0.	0.
HEATING OIL	0.	0.	102.	0.	0.	0.	0.
ELECTRICITY	475.	358.	271.	271.	366.	366.	366.
TOTAL FUEL	475.	358.	373.	338.	366.	366.	366.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	107.	0.	0.	0.
HEATING OIL	0.	0.	147.	0.	0.	0.	0.
ELECTRICITY	582.	439.	332.	332.	448.	448.	448.
TOTAL ANNUALIZED FUEL	582.	439.	479.	440.	448.	448.	448.
TOTAL FUEL COST	9523.	7172.	7840.	7189.	7327.	7327.	7327.
TOTAL ANNUALIZED COST	827.	689.	822.	691.	649.	827.	1032.
TOTAL LIFE CYCLE COST	13525.	11268.	13437.	11296.	10603.	13517.	16876.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-2258.	-89.	-2229.	-2917.	-9.	3350.
FIRST YEAR- DELTA EQUIP COST	0.	80.	1370.	90.	-620.	1880.	4767.
DELTA FUEL & OP COST	0.	-115.	-88.	-136.	-115.	-90.	-61.
PAYBACK (YRS)	(-)	1.00	15.52	1.00	1.00	20.84	77.72

* - INDICATES STANDARD MODEL GROUND WATER HEAT PUMP

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN HOUSTON, TEXAS

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3440.	3520.	4810.	3530.	3080.	5580.	8467.
ANNUALIZED - EQUIP.	210.	215.	294.	216.	188.	341.	518.
OP. & MAINT.	34.	35.	48.	35.	31.	56.	85.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	67.	0.	0.	0.
HEATING OIL	0.	0.	102.	0.	0.	0.	0.
ELECTRICITY	475.	358.	271.	271.	329.	329.	329.
TOTAL FUEL	475.	358.	373.	338.	329.	329.	329.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	107.	0.	0.	0.
HEATING OIL	0.	0.	147.	0.	0.	0.	0.
ELECTRICITY	582.	439.	332.	332.	402.	402.	402.
TOTAL ANNUALIZED FUEL	582.	439.	479.	440.	402.	402.	402.
TOTAL FUEL COST	9523.	7172.	7840.	7189.	6581.	6581.	6581.
TOTAL ANNUALIZED COST	827.	689.	822.	691.	622.	800.	1005.
TOTAL LIFE CYCLE COST	13525.	11268.	13437.	11296.	10165.	13073.	16432.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-2258.	-89.	-2229.	-3361.	-452.	2907.
FIRST YEAR- DELTA EQUIP COST	0.	80.	1370.	90.	-360.	2140.	5027.
DELTA FUEL & OP COST	0.	-114.	-88.	-136.	-150.	-125.	-96.
PAYBACK (YRS)	(-)	1.00	15.52	1.00	1.00	17.17	52.51

* - INDICATES ~~STANDARD~~ MODEL GROUND WATER HEAT PUMP

High eff.

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN PHILADELPHIA, PENNSYLVANIA

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3650.	3770.	5090.	3740.	3450.	5130.	7318.
ANNUALIZED - EQUIP.	223.	231.	311.	229.	211.	314.	448.
OP. & MAINT.	37.	38.	51.	37.	35.	51.	73.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	283.	0.	0.	0.
HEATING OIL	0.	0.	399.	0.	0.	0.	0.
ELECTRICITY	957.	532.	112.	112.	385.	385.	385.
TOTAL FUEL	957.	532.	511.	395.	385.	385.	385.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	397.	0.	0.	0.
HEATING OIL	0.	0.	581.	0.	0.	0.	0.
ELECTRICITY	1042.	580.	122.	122.	419.	419.	419.
TOTAL ANNUALIZED FUEL	1042.	580.	704.	520.	419.	419.	419.
TOTAL FUEL COST	17044.	9483.	11504.	8500.	6851.	6851.	6851.
TOTAL ANNUALIZED COST	1302.	848.	1066.	786.	664.	784.	940.
TOTAL LIFE CYCLE COST	21291.	13869.	17426.	12852.	10865.	12820.	15366.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-7421.	-3865.	-8439.	-10426.	-8471.	-5925.
FIRST YEAR- DELTA EQUIP COST	0.	120.	1440.	90.	-200.	1480.	3668.
DELTA FUEL & OP COST	0.	-424.	-432.	-561.	-574.	-557.	-535.
PAYBACK (YRS)	(-)	1.00	3.34	1.00	1.00	2.66	6.85

* - INDICATES HIGH EFFICIENCY MODEL GROUND WATER HEAT PUMP

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN SEATTLE, WASHINGTON

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3650.	3515.	5090.	3740.	3450.	5230.	7554.
ANNUALIZED - EQUIP.	223.	215.	311.	229.	211.	321.	462.
OP. & MAINT.	37.	35.	51.	37.	35.	53.	75.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	416.	0.	0.	0.
HEATING OIL	0.	0.	403.	0.	0.	0.	0.
ELECTRICITY	370.	174.	19.	19.	138.	138.	138.
TOTAL FUEL	370.	174.	422.	435.	138.	138.	138.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	562.	0.	0.	0.
HEATING OIL	0.	0.	589.	0.	0.	0.	0.
ELECTRICITY	462.	217.	23.	23.	173.	173.	173.
TOTAL ANNUALIZED FUEL	462.	217.	612.	585.	173.	173.	173.
TOTAL FUEL COST	7554.	3547.	10004.	9569.	2825.	2825.	2825.
TOTAL ANNUALIZED COST	722.	467.	974.	851.	418.	546.	710.
TOTAL LIFE CYCLE COST	11831.	7637.	15926.	13921.	6839.	8933.	11614.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-4164.	4125.	2120.	-4962.	-2967.	-187.
FIRST YEAR- DELTA EQUIP COST	0.	-135.	1440.	90.	-200.	1680.	3904.
DELTA FUEL & OP COST	0.	-197.	66.	66.	-234.	-216.	-193.
PAYBACK (YRS)	(-)	1.00	1.00	1.00	1.00	7.41	20.22

* - INDICATES HIGH EFFICIENCY MODEL GROUND WATER HEAT PUMP

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN TULSA, OKLAHOMA

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3610.	4340.	4960.	3700.	2990.	4990.	7424.
ANNUALIZED - EQUIP.	221.	265.	303.	226.	183.	305.	454.
OP. & MAINT.	36.	43.	50.	37.	30.	50.	74.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	208.	0.	0.	0.
HEATING OIL	0.	0.	323.	0.	0.	0.	0.
ELECTRICITY	765.	443.	117.	117.	364.	364.	364.
TOTAL FUEL	765.	443.	440.	325.	364.	364.	364.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	333.	0.	0.	0.
HEATING OIL	0.	0.	467.	0.	0.	0.	0.
ELECTRICITY	937.	543.	143.	143.	447.	447.	447.
TOTAL ANNUALIZED FUEL	937.	543.	610.	476.	447.	447.	447.
TOTAL FUEL COST	15317.	8877.	9972.	7787.	7301.	7301.	7301.
TOTAL ANNUALIZED COST	1194.	852.	963.	740.	659.	802.	975.
TOTAL LIFE CYCLE COST	19517.	13927.	15743.	12092.	10780.	13107.	15939.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-5591.	-3774.	-7425.	-8737.	-6410.	-3578.
FIRST YEAR- DELTA EQUIP COST	0.	730.	1350.	90.	-620.	1380.	3814.
DELTA FUEL & OP COST	0.	-315.	-312.	-439.	-407.	-387.	-363.
PAYBACK (YRS)	(-)	2.32	4.33	1.00	1.00	3.56	10.51

* - INDICATES STANDARD MODEL GROUND WATER HEAT PUMP

ECONOMIC EVALUATION OF HEATING/COOLING SIMULATION IN TULSA, OKLAHOMA

ECONOMIC ANALYSIS PARAMETERS

BEGINNING YR. OF SIM.	1980.
ANALYSIS PERIOD (YRS)	20.
REFERENCE SYSTEM	1.
REAL DISCOUNT RATE	2.0 %
CAPITAL RECOVERY FACTOR	0.0612
OPER. AND MAINT. RATE	1.0 %

EQUIPMENT COST SUMMARY - 1980 INSTALLATION (IN 1979 DOLLARS)

ITEM	ELECTRIC RESISTANCE	AIR HEAT PUMP	OIL	NATURAL GAS	* WATER HEAT PUMP	* WATER HP INJ.WELL	* WATER HP SUP.WELL & INJ.WELL
EQUIPMENT	3610.	4340.	4960.	3700.	3420.	5428.	7954.
ANNUALIZED - EQUIP.	221.	265.	303.	226.	209.	331.	480.
OP. & MAINT.	36.	43.	50.	37.	34.	34.	79.
FIRST YEAR FUEL							
NATURAL GAS	0.	0.	0.	208.	0.	0.	0.
HEATING OIL	0.	0.	323.	0.	0.	0.	0.
ELECTRICITY	765.	443.	117.	117.	337.	337.	337.
TOTAL FUEL	765.	443.	440.	325.	337.	337.	337.
ANNUALIZED FUEL COST							
NATURAL GAS	0.	0.	0.	333.	0.	0.	0.
HEATING OIL	0.	0.	467.	0.	0.	0.	0.
ELECTRICITY	937.	543.	143.	143.	413.	413.	413.
TOTAL ANNUALIZED FUEL	937.	543.	610.	476.	413.	413.	413.
TOTAL FUEL COST	15318.	8878.	9972.	7737.	6752.	6752.	6752.
TOTAL ANNUALIZED COST	1194.	852.	963.	740.	656.	799.	972.
TOTAL LIFE CYCLE COST	19513.	13928.	15743.	12092.	10731.	13058.	15890.
PRESENT WORTH OF- TOTAL NET BENEFIT	0.	-5591.	-3775.	-7426.	-8787.	-6460.	-3628.
FIRST YEAR-							
DELTA EQUIP COST	0.	730.	1350.	90.	-190.	1810.	4244.
DELTA FUEL & OP COST	0.	-315.	-312.	-439.	-430.	-410.	-384.
PAYBACK (YRS)	(-)	2.32	4.33	1.00	1.00	4.42	11.02

* - INDICATES HIGH EFFICIENCY MODEL GROUND WATER HEAT PUMP

APPENDIX E

PAYBACK PERIODS

Simple Payback Period (Years):

GWHP System vs. Air-to-Air Heat Pump

City	With No Wells	With Injection Well	With Supply & Injection Wells
Atlanta	*	11.9	>
Birmingham			
High Eff.	*	14.3	>
Standard	*	9.7	>
Cleveland	*	5.2	15.7
Columbus	*	7.3	20.0
Concord			
High Eff.	*	4.4	12.5
Dir. Cooling	*	2.5	6.3
Houston			
High Eff.	*	>	>
Standard	*	>	>
Philadelphia	*	10.2	>
Seattle	*	>	>
Tulsa			
High Eff.	*	11.3	>
Standard	*	9.0	>

*GWHP costs less at installation

>More than 20 years

NOTE: Courtesy of NWWA

Simple Payback Period (Years):

GWHP System vs. Oil

City	With No Wells	With Injection Well	With Supply & Injection Wells
Atlanta	*	*	13.1
Birmingham			
High Eff.	*	*	16.3
Standard	*	*	13.7
Cleveland	*	*	14.4
Columbus	*	1.1	
Concord			
High Eff.	*	>	>
Dir. Cooling	*	3.4	>
Houston			
High Eff.	*	>	>
Standard	*	>	>
Philadelphia	*	0.3	>
Seattle	*	0.6	9.5
Tulsa			
High Eff.	*	4.7	>
Standard	*	0.4	>

*GWHP costs less at installation

>More than 20 years

NOTE: Courtesy of NWWA

Simple Payback Period (Years):

GWHP System vs. Gas

City	With No Wells	With Injection Well	With Supply & Injection Well
Atlanta	*	>	>
Birmingham			
High Eff.	*	>	>
Standard	*	>	>
Cleveland	*	>	>
Columbus	*	>	>
Concord			
High Eff.	*	>	>
Dir. Cooling	*	19.7	>
Houston			
High Eff.	*	>	>
Standard	*	>	>
Philadelphia	*	>	>
Seattle	*	5.4	14.7
Tulsa			
High Eff.	*	>	>
Standard	*	>	>

*GWHP costs less at installation

>More than 20 years

NOTE: Courtesy of NWWA

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